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Directorate: Communications Systems

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Title: Conceptual Design of a Switched Television-Distribution System Using Optical-Fiber Waveguides

Author(s): Elmer H. Hara

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1. INTRODUCTION

Recent development of optical fiber waveguides with losses less than 1 dB/km at 950 nm wavelength[1] has created the possibility of transmitting television signals through analogue optical transmission systems for distances extending well beyond 10 km, without the use of repeaters[2]. Analogue systems are attractive because of system simplicity and potential low cost in comparison to digital optical transmission systems. Application of optical fibers to cable television (CATV) systems have been discussed often in the past[3,4,5,6] and two fundamental problems in duplicating the present coaxial cable television system with optical fibers have been identified.

The first problem is the possible limitation in the transmission bandwidth of the easy-to-use optical fibers[7]. The transmission of cable television signals over distances of more than several kilometers is difficult for most optical fibers because of the bandwidth requirement that exceeds 200 MHz. Therefore, for trunk-lines in optical cable television systems, spatial division multiplexing may need to be considered.

The second problem is the large optical input power required if many subscribers are to be connected to a single light source. For example, if 1 μW is to be delivered to each of five thousand subscribers, a total of more than 5 mW will need to be launched into the fiber at the signal source. This assumes that there are no intervening losses such as fiber loss and coupling losses. Such losses will increase the required power many times. High power light sources are limited to gas or Nd^{3+}:YAG lasers which are bulky and not generally suited for application to optical communication systems for local subscriber loops.

The conventional coaxial cable television system therefore appears to be difficult to reproduce within the context of present optical communications technology. However, the switched cable television systems of "Rediffusion" (England) and "Discade" (USA) can be duplicated readily by using optical fibers because, at any given time, only a single TV channel is supplied to the subscriber through a line that is dedicated to the subscriber. Channel selection is performed by the subscriber but the switching is carried out at a distribution (switching) centre. The switching signal is carried from the subscriber back to the distribution centre, through the dedicated line.

Since optical-fiber transmission systems are immune to RF interference, and distances extending well beyond 5 km can be spanned by analogue optical transmission methods, the switched optical-fiber system merits consideration. A conceptual design of a switched television-distribution system using optical fibers is presented in this memorandum and some design options are discussed.

2. SWITCHED TELEVISION-DISTRIBUTION SYSTEM

The distribution system described here provides two TV channels by frequency division multiplexing (FDM) and one baseband audio channel to the subscriber. Two TV channels were considered essential because many Canadian homes have two TV sets that are used to view two different channels simultaneously, one by adults and the other by children. An audio channel is included to allow data transmission or connection of a telephone system.

A return line to the central switching office carries two tone-signals on subcarrier frequencies for TV channel selection and one baseband audio signal for data or telephone.

2.1 Subscriber Station

A block diagram of the subscriber station is shown in Fig. 1. Two optical fibers are used to connect the subscriber to the central switching office. Since optical fibers are difficult to use in a bi-directional manner at present, one fiber is used for transmission to the subscriber while the other fiber is used for transmission to the central switching office. The FDM signal is transmitted from the central switching office as an intensity modulated (IM) optical analogue signal. The optical signal is detected by a photodiode and the radio frequency (RF) signals are separated into baseband audio and the two TV subcarrier frequencies f_1 and f_2, by the power splitter and filters. The subcarrier frequencies carry amplitude modulated (AM) video signals and frequency modulated (FM) audio signals according to the National Television Standardization Committee (NTSC) format. The two TV signals are demodulated to produce baseband video signals and FM audio signals at 4.5 MHz. The signals are then supplied to TV sets designed to receive these signals through a hard-wire connection. The baseband audio signal is also connected by hard-wire to a data terminal or telephone set depending on the subscriber's requirement.

Channel selection for the TV sets is performed through a 12-key "Touch-Tone" pushbutton pad. The tone-signals are modulated on to subcarrier frequencies (f_1',f_2') and combined to produce an FDM signal.

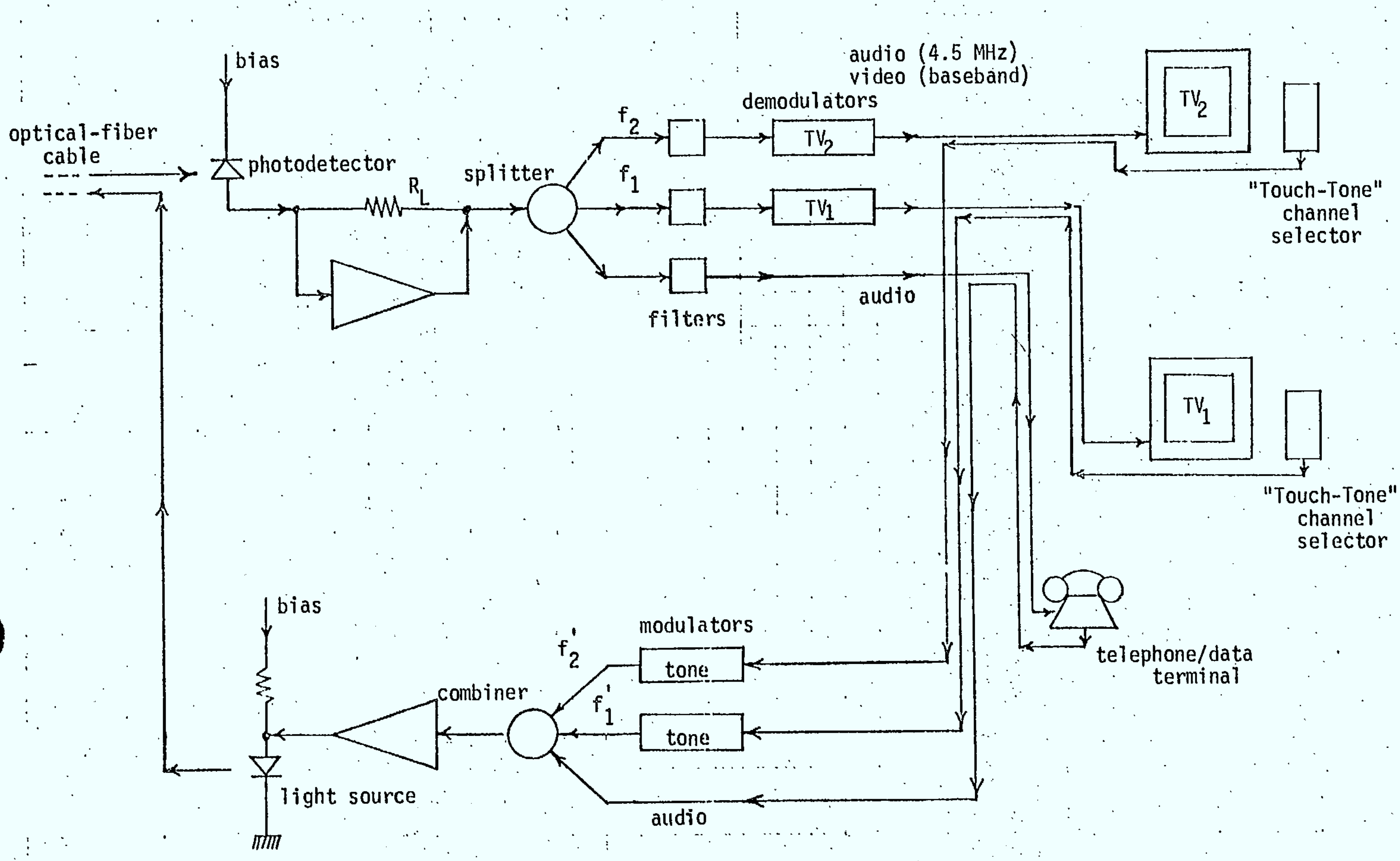
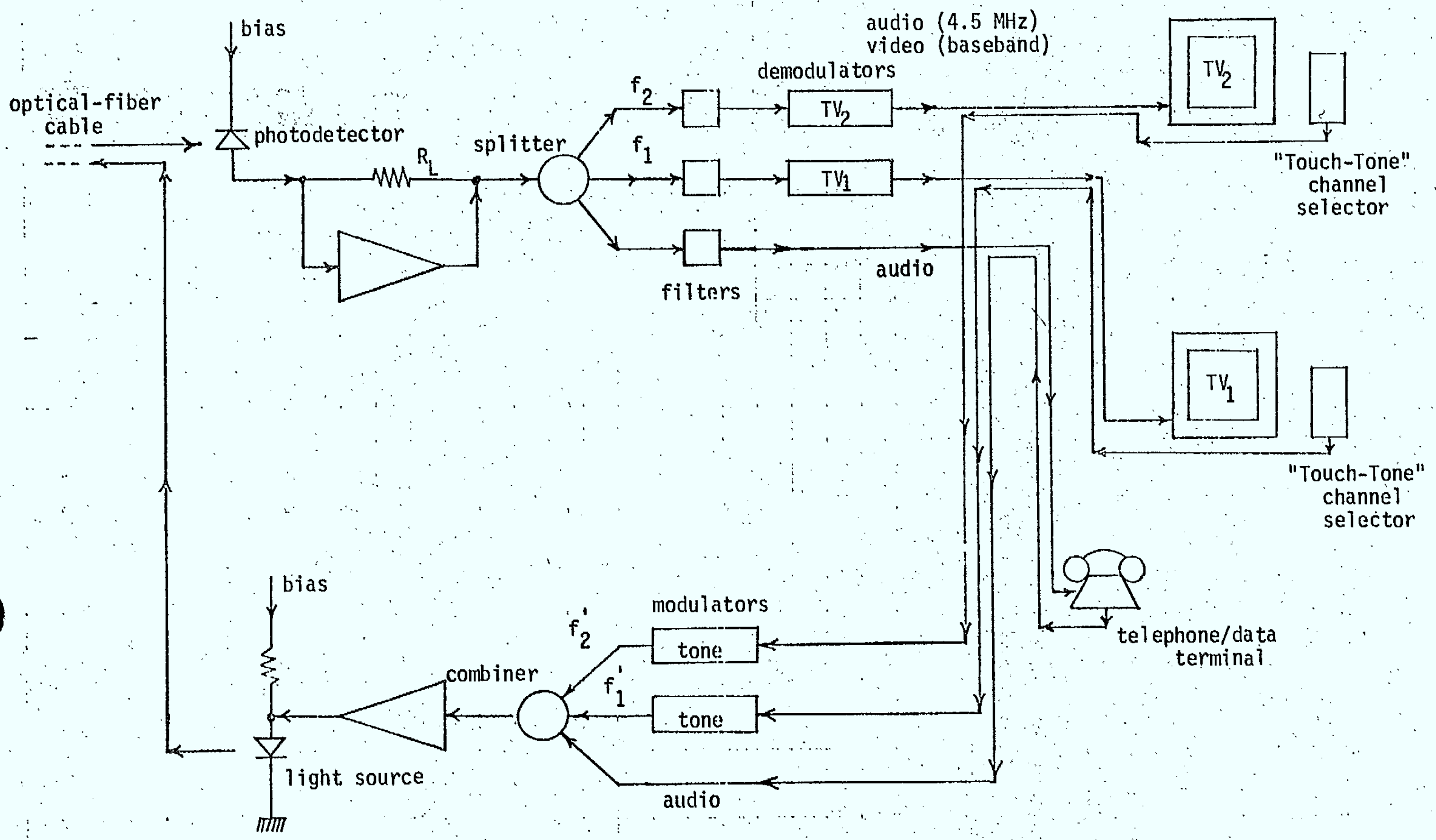


Fig. 1 SUBSCRIBER STATION

Two optical-fibers are connected to the subscriber. One fiber brings in 2 TV channels and a baseband audio signal from the switching office while the second fiber sends out 2 "Touch-Tone" signals for TV channel selection and a baseband audio signal to the switching office.



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The tone signals are carried as FM signals by subcarrier frequencies f_1 and f_2. Whenever the TV set is energized a subcarrier frequency is produced to indicate to the central processor unit at the switching centre that a set is in use. The combiner also introduces the baseband audio signal from the data terminal or telephone set. The combined FDM signal is used to modulate a light source to produce an IM optical analogue signal. The optical signal is then transmitted to the central switching office through the second optical fiber.

Possible allocation of frequencies for the FDM scheme is shown in Table 1. The subcarrier frequencies for TV transmission and channel-selection tone-signals are chosen so that second order intermodulation products do not interfere with the quality of transmission.

2.2 Central Switching Office

A block diagram of the central switching office is shown in Fig. 2. Two optical fibers connect each subscriber to the office. The figure shows only two sets of pairs for simplicity. The IM optical analogue signal is detected by a photodiode first and then the RF subcarrier and baseband signals are separated through a power splitter and filters. The baseband audio signal is hard-wire connected to a telephone exchange which provides the data or telephone service. The channel-selection tone-signals are first recovered by demodulating the FM subcarrier signals and then supplying them to the switching system which selects the appropriate TV channels according to the switching codes that are received.

The switching system has a number of TV signal sources. Some are received off-air, others through microwave links or satellite links.

TABLE 1

FREQUENCY ALLOCATION OF RF SUBCARRIERS

The TV frequencies correspond to channel T-8 and T-9 of the sub-low bands.

To Subscriber		
Service	Frequency (MHz)	Modulation
Audio	baseband	
TV_1 Video Audio (NTSC Format)	13.0 17.5	AM FM
TV_2 Video Audio (NTSC Format)	19.0 23.5	AM FM

From Subscriber		
Service	Frequency (MHz)	Modulation
Audio	baseband	
Channel Selection Tone	0.10	FM
Channel Selection Tone	0.15	FM

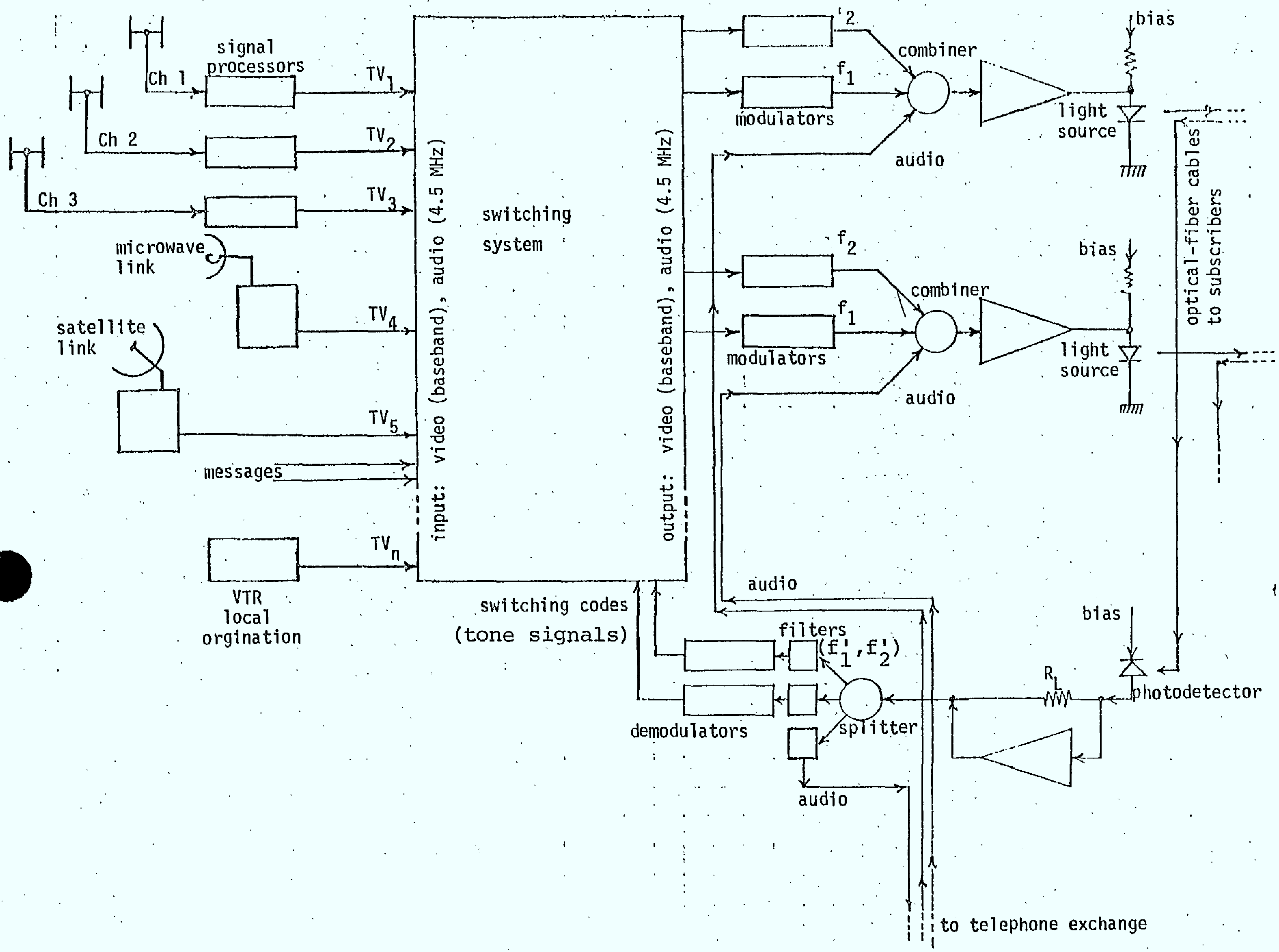

Fig. 2 CENTRAL SWITCHING OFFICE

A large number of TV channels can be offered by using off-the-air, microwave and satellite signals in addition to locally originated programs. The baseband audio signals are connected to a telephone or data exchange system.

Local origination may include a video tape recorder or signals produced in a TV studio. Appropriate voice messages are also provided to inform the subscriber of any unusual problems. The video signals are supplied to the switching system at baseband while the audio signals are carried by FM on a 4.5 MHz subcarrier frequency.

The TV channels or voice messages are connected by the switching system to the modulator which imposes the signals upon subcarrier frequencies f_1 and f_2 and then passes them to the light source to generate an analogue IM optical signal which is transmitted to the subscriber through an optical fiber. The baseband audio signals that provide the data or telephone service are also combined with the TV signals to complete the FDM transmission scheme. Thus, a subscriber may receive simultaneously up to two TV channels and an audio signal which may provide either data or telephone service.

2.3 Switching System

A block diagram of the switching system is shown in Fig. 3. Two switching matrices are used, one for the channel-selection tone-signals and one for the TV signals. The switching matrices are controlled by a central processing unit (CPU) which can close a circuit at any cross-point in the switching matrices. The subscriber lines are scanned continuously for the presence of two signals, the "#"-tone and the subcarriers f_1' and f_2'. The "#"-tone is generated by the "Touch-Tone" channel selector at the TV set and signifies a request by the subscriber to change the TV channel being viewed. The subcarriers f_1' and f_2' when demodulated, provide a DC signal which indicates that the TV set is in use.

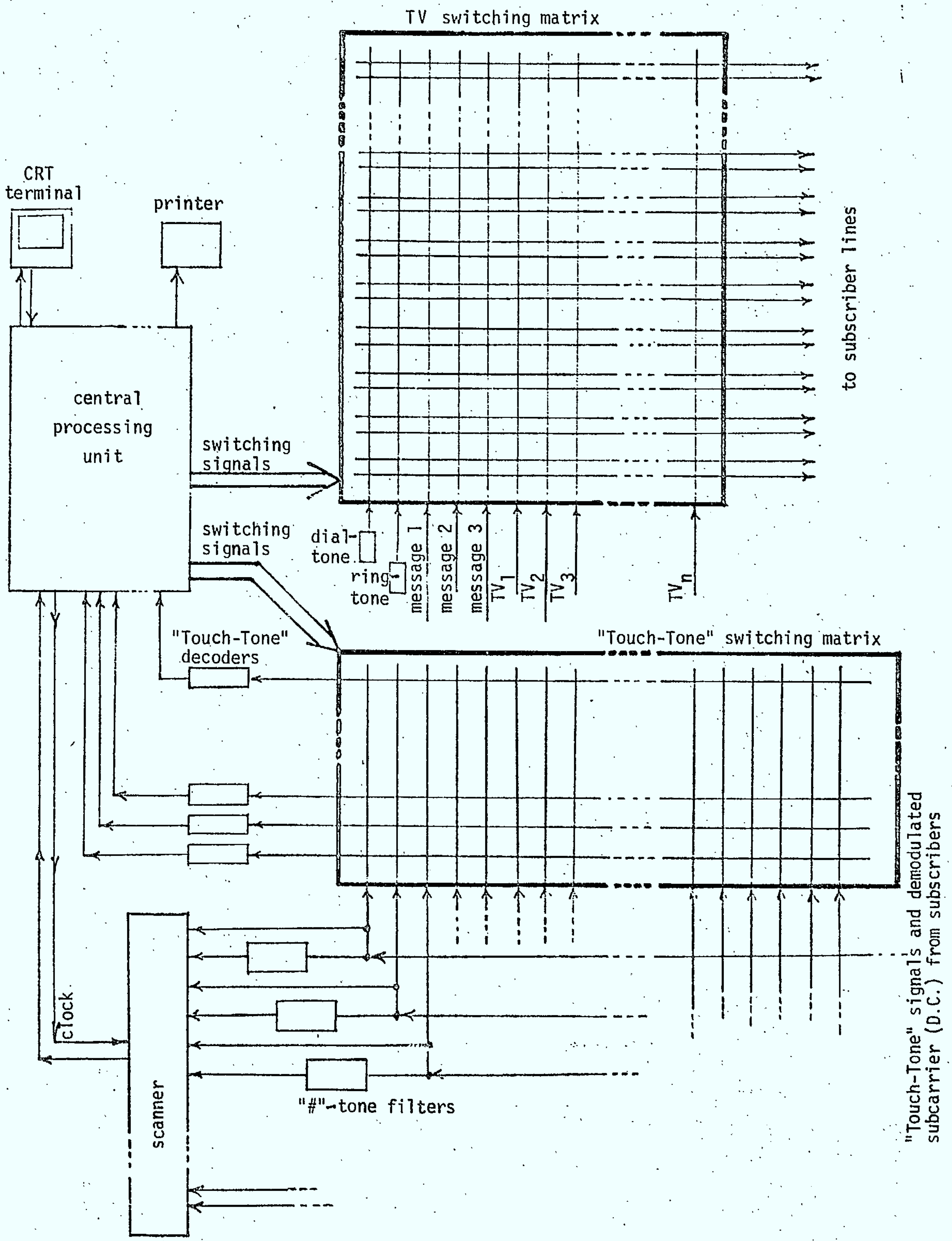

Fig. 3 SWITCHING SYSTEM

The "Touch-Tone" switching matrix is used to connect decoders to the in-coming lines from the subscribers. The TV switching matrix is controlled by the central processing unit (CPU) which is programmed to respond to various situations. The CPU may also be used for data processing operations such as statistical analysis for program ratings and customer account billing.

contained in the CPU enables the CPU to identify each TV channel and every subscriber so that appropriate switching is provided and pertinent data is recorded for accounting purposes and statistical analysis.

A flow chart for the CPU program logic for TV channel selection is shown in Fig. 4. Once the "#"-tone is detected, the CPU resets the switching process for the particular subscriber to the reset point. If the condition indicates a change in the TV channel being viewed, data such as viewing times, duration, channel number, type of service (i.e. Pay-TV, Subscription-TV or Free-TV)[†] are recorded first. The CPU then searches for a "Touch-Tone" decoder to connect to the subscriber's line. The connection is made by closing one of the cross-points in the "Touch-Tone" switching matrix. If all decoders are in use, a voice message is provided to inform the subscriber and request a second dialing attempt a short time later. The message is a pre-recorded announcement and is connected to the subscriber's line by closing a cross-point in the TV switching matrix. The dial-tone and ring-tone are connected in the same manner. Once a decoder is connected, a dial-tone is supplied to inform the subscriber that the CPU is prepared to receive a channel selection code. If the subscriber is tardy in his selection, the dial-tone and decoder are disconnected after a suitable time lapse. Termination of the dial-tone indicates to the subscriber that the CPU has disconnected him. This step is introduced to make efficient use of the decoders.

When the two-digit tone-codes for channel selection are decoded and received by the CPU, a ring-tone is supplied to inform the subscriber that the switching operation has started. If a Pay-TV or Subscription-TV

[†] Pay-TV refers to a TV service based on a charge per program scheme while subscription-TV refers to TV service based on a fixed monthly or annual charge scheme. Free-TV service refers to public broadcasting services.

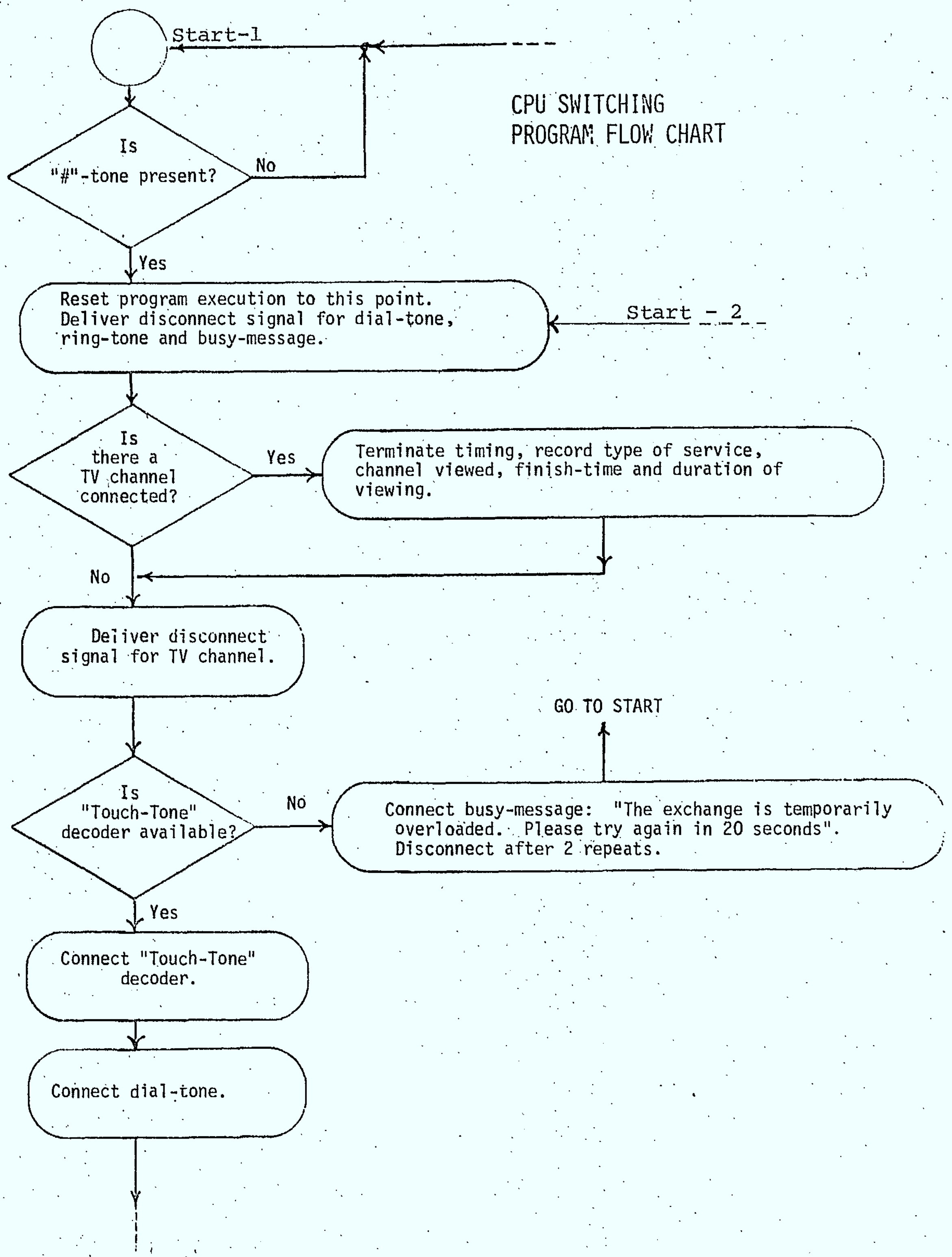
Start-1
CPU SWITCHING
PROGRAM FLOW CHART
Is
"#"-tone present?
No
Yes
Reset program execution to this point.
Deliver disconnect signal for dial-tone,
ring-tone and busy-message.
Start - 2
Is
there a
TV channel
connected?
Yes
Terminate timing, record type of service,
channel viewed, finish-time and duration of
viewing.
No
Deliver disconnect
signal for TV channel.
GO TO START
Is
"Touch-Tone"
decoder available?
No
Connect busy-message: "The exchange is temporarily
overloaded. Please try again in 20 seconds".
Disconnect after 2 repeats.
Yes
Connect "Touch-Tone"
decoder.
Connect dial-tone.

Fig. 4

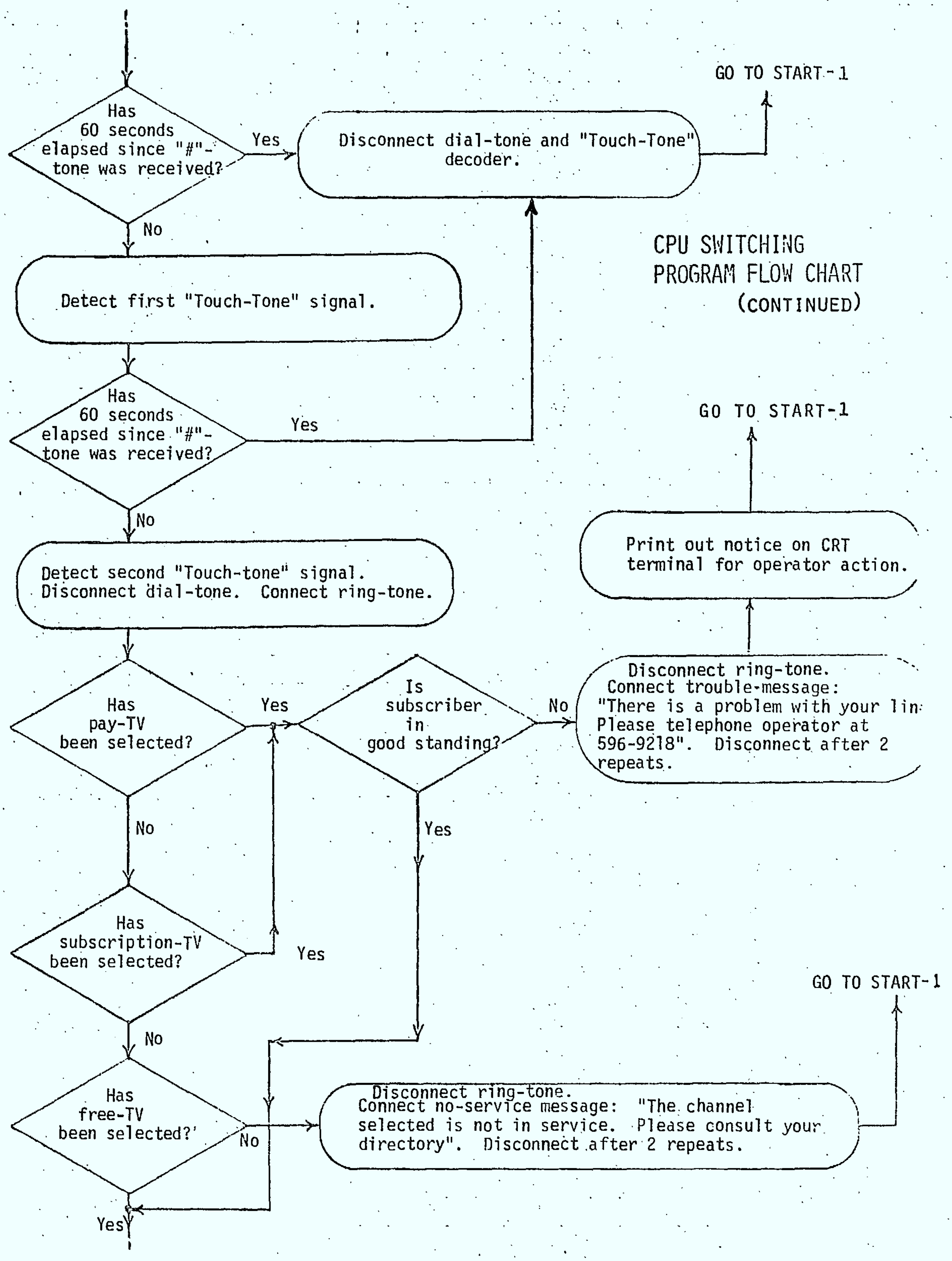

Fig. 4 (continued)

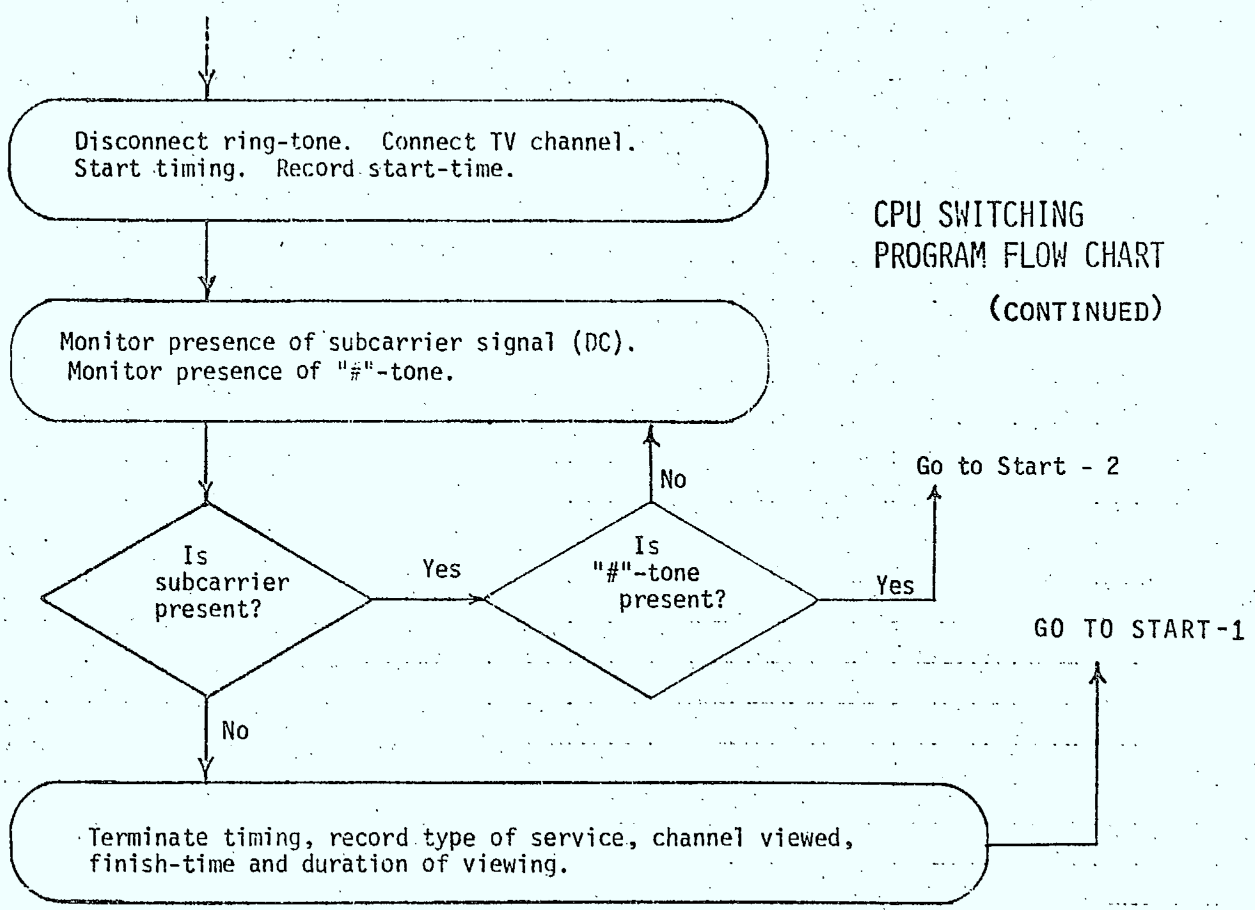

Fig. 4 FLOW CHART OF THE CPU SWITCHING PROGRAM

Branching points are provided to cope with various conditions encountered in processing subscriber requests.

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service has been selected, the CPU is programmed to check the accounts of the subscriber for any arrears. If a significant amount is owing, a message is connected requesting the subscriber to contact the operator. At the same time the operator is alerted by a printout on the cathode ray tube (CRT) terminal which provides pertinent information about the subscriber's account. When the subscriber contacts the operator, ways of rectifying the problem can be discussed and manual intervention by the operator may optionally allow the subscriber to receive the TV signal on a limited basis. If the subscriber does not contact the operator, the operator may phone the subscriber to initiate a discussion on ways of rectifying the problem.

In case a channel that is not in service is selected, a message informing the subscriber to consult the TV channel directory is provided. If the customer's account is in good standing or Free-TV service has been selected, the ring-tone is disconnected and the TV channel is connected by the CPU which closes the appropriate cross point in the TV switching matrix. At the same time, the start-time of viewing is recorded for accounting or statistical purposes. The TV channel remains connected as long as the presence of the subcarrier signal (DC) of the channel-selection tone-signal is detected by the CPU scanning. If a "#"-tone is detected by the scanning, the channel selection is initiated from the beginning again. If the TV set is turned off, the timing is terminated by the CPU because the subcarrier signal is terminated. The type of service provided, channel number, finish-time and duration of viewing are then recorded for accounting or statistical use.

The actions required of the subscriber to obtain TV service are described in the flow chart shown in Fig. 5. Use of the "Touch-Tone" channel selector is much like that of the telephone except that the "#" button must be pushed in place of the action of lifting the hand-set off the cradle. The actions to follow are similar to those required in the normal operation of the telephone and no difficulty should be experienced by the average subscriber. In case of difficulty, the operator on duty at the central switching office may intervene manually through the CPU, provided the control program is suitably written to detect malfunctions and provide information to the operator through the CRT or printer.

3. DESIGN OPTIONS

The switched television distribution system described in the previous section is based on an FDM scheme where two TV signals are transmitted through subcarrier frequencies while the audio (telephone, data) signals are transmitted at baseband to the subscriber. Return signals to the central switching office from the subscriber are transmitted by an FDM scheme where the two TV channel-selection tone-signals are imposed on sub-carrier frequencies and the audio (telephone, data) signals are transmitted at baseband. Only two fibers, one for transmission to the subscriber and one for transmission back to the central switching office, are required. Depending on the cost and quality of performance, a number of modifications in the configuration of the system can be considered. In the following sections some of the design options are discussed.

3.1 Spatial Division Multiplexing

In place of the FDM transmission scheme, a spatial division multiplexing (SDM) scheme where each video signal is transmitted as a

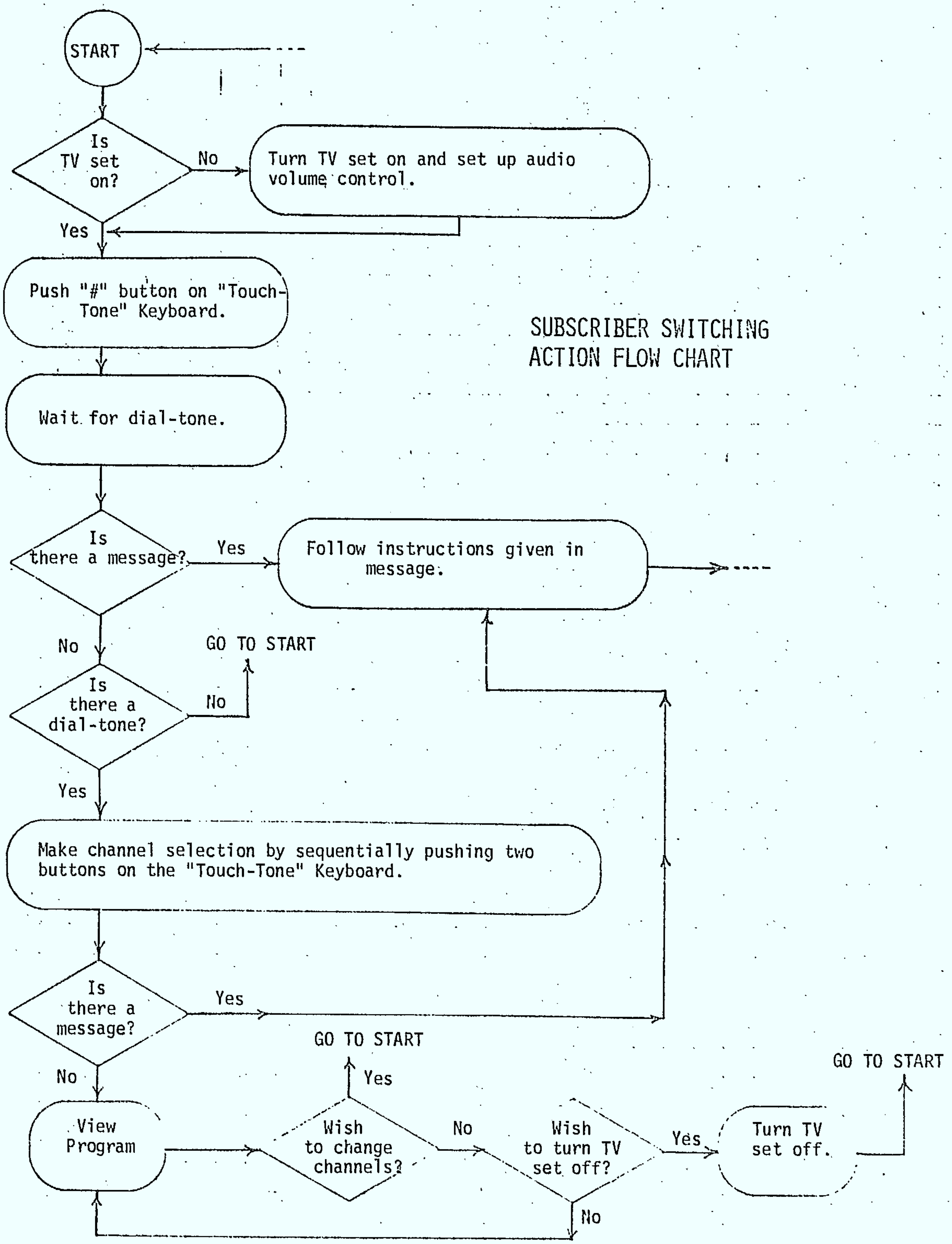

Fig. 5 FLOW CHART FOR SUBSCRIBER SWITCHING ACTION

The steps for channel selection are identical to those for the telephone system except for the action of pushing the "#"-button. The action is equivalent to lifting the telephone hand-set off the cradle.

baseband signal can be considered. In such a case, each TV channel will require an independent optical fiber for transmission to the subscriber. Thus, in addition to the fiber for return transmission from the subscriber, there will be 3 fibers, 1 each for the 2 TV channels and 1 for the audio (telephone, data) signals. The TV signals will consist of the baseband video signal and the 4.5 MHz FM audio signal. The audio fiber from the switching office may be excluded if no telephone or data service is to be offered. Each of the fibers will be connected to individual photodetectors which provide signals to TV sets and audio terminals. Since splitters, filters and demodulators will not be required, the subscriber station is simplified somewhat, except for the increase in the number of photodetection units. The transmission circuitry at the central switching station will also be simplified by the elimination of the modulators and combiners for each subscriber but each fiber will require an individual light source and driver circuitry. The return signals from the subscriber to the central switching office are audio signals and are best transmitted as FDM signals as shown in the original design because the electronic circuitry is simple and inexpensive for the frequencies and bandwidths that are involved.

A total of 4 fibers will therefore be required to provide simultaneous service of 2 TV channels and an audio frequency link. The cost increase due to the extra fibers should be off-set by simplification in the electronic circuitry. In comparison to the FDM scheme, the SDM scheme will require less transmission bandwidth for each fiber and be advantageous for transmission over distances longer than that possible in the FDM scheme. Whether the SDM transmission scheme described above is more suitable for practical applications will depend on many factors such as transmission distance, optical power launched into the fiber and system noise levels. Both FDM and SDM designs will most likely be useful depending on particular cases.

3.2 Switching of FDM Signals

The design of the central switching office shown in Fig. 2 has modulators for each TV set in order to provide signals suited for an FDM transmission scheme. Since each TV set requires a modulator, elimination of the modulators would represent a significant savings in cost and simplification in the electronic circuitry. This can be achieved if the TV switching matrix can provide sufficient isolation at the subcarrier frequencies, f_1 (13.0 MHz) and f_2 (19.0 MHz). At present, commercial semiconductor switches that offer the most cost effective method for video switching have not been tested thoroughly for application at these frequencies†.

If we assume that a satisfactory TV switching matrix is available, redesign of the central switching office is straight forward. The outputs from the switching system are connected directly to the driver for the light source through the combiner. For each TV channel to be offered to the subscribers, a signal processor that produces 2 TV signals at frequencies f_1 (13.0 MHz) and f_2 (19.0 MHz) from a single TV signal source is used. The 2 signals are then supplied to the TV switching system. Commercial signal processors may be used by dividing the intermediate frequency (IF) output and connecting it to 2 IF-to-Channel converters which produce the 2 TV signals at frequencies f_1 and f_2.

† The design of TV switching matrices are discussed in Appendix F.

By shifting the up-conversion of TV signals to the input side of the TV switching matrix, we see that a substantial simplification in the system can be realized. Since only a minimum number of signal processors are required, high quality units can be used to provide a good TV signal, without unduly affecting the system cost per subscriber.

3.3 Power Source

The question of whether electrical power for the operation of subscriber terminals should be supplied from the central switching office or be obtained locally from the subscriber's household arises. Supplying power from the central switching office has the advantage of maintaining an audio transmission link even in the event of a power failure in the subscriber's household. Also, power for repeater amplifiers, if required for long distance transmission in rural areas, will be available. In such a power scheme, a copper-wire pair must be included in the optical-fiber cable.

If a copper-wire pair is included in the cable, the same pair of wires can carry audio signals bidirectionally in addition to the electrical power which is the case with the present telephone system. This means that the optical fiber returning to the central switching office is not required and the system will be simplified. Channel selection for TV can be made over the copper-wire pair in same manner as previously described except that lower subcarrier frequencies compatible with the frequency response of the copper-wire pair must be used in the FDM scheme.

For the FDM TV transmission scheme, only a single optical-fiber will be needed and in the SDM TV transmission scheme, 2 optical fibers will be needed in addition to the copper-wire pair. A detailed system analysis will be required to clarify the merits of the various systems. However, if a return fiber to the central switching office is not provided, the possibility of future expansion to a switched broadband service such as video telephone, will not be available.

In view of recent developments in lead-acid storage batteries†, the problems associated with power failures in local power sources may be eliminated. The high energy density and compactness of the new batteries will make it possible to design subscriber and repeater equipment that will still function normally in the event of a local power failure.

3.4 Radio Service

If radio service is to be provided as well, a separate radio switching matrix can be introduced in addition to the TV switching matrix. The transmission mode can be FM on a suitable RF subcarrier frequency such as 200 KHz. The signal may be transmitted together with the TV signals as a component of the FDM scheme. Receivers will require a "Touch-Tone" station selector in place of the usual tuning-dial. The selector on the TV set may be used as the station selector as well. Demodulation of the FM signal can be accomplished readily by phase-lock loop techniques using integrated circuits[8].

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† See for example, advertisements for the new lead-acid batteries offered by Gates Energ Products, Inc. (e.g. IEEE Spectrum, Vol. 13, No. 1, January 1976, back cover.).

Rather than provide only a single radio signal at any given time, a number of signals may be provided simultaneously by transmitting many FM subcarrier signals within a suitable frequency range such as between 200 kHz and 1 MHz. Demodulation is readily accomplished by phase-lock loop techniques and station selection is possible by simple adjustment of a variable resistor[9]. Connection of the radio signals to the subscriber will still rely on a switching matrix which is activated through a "Touch-Tone" request signal.

4. SYSTEM COMPONENTS

Optical communications technology has developed components that make the conceptual designs considered here technically feasible. The associated electronic components required are of standard commercial quality and no difficulty should be encountered in assembling the required subsystems. The key components are discussed briefly below.

4.1 Optical-Fiber Waveguide

We expect that single-strand fiber waveguides will be used as the standard in the future because of the lower cost in comparison to the bundled fiber design where many fibers are used to form a single transmission line. The fiber strength is expected to be such that breakage due to handling during installation will not be a problem.

Losses less than 1 dB/km at 1.1 μm wavelength have been recorded in the laboratory and optical fiber cables with losses less than 15 dB/km are being offered commercially now. Table 2 lists the specifications of 2 cables while Table 3 lists specifications for uncabled optical fibers.

TABLE 2

OPTICAL-FIBER CABLE SPECIFICATIONS

Specifications and test data of the Corguide(TM) cable manufactured by Corning Glass Works (USA) are listed.

Type	Loss (dB/km) @ λ = 900 nm	Transmission Bandwidth (km Mb/s)	Cost† ($/m)
graded-index	20	200	13.50
graded-index	12	200	18.75

† The cost is for a cable containing 6 separate optical fibers. Future cost, assuming large scale production by cable companies, is expected to be less than 40¢/m per fiber which is comparable to the cost of copper wire pair.

TABLE 2 (continued)

CORGUIDE™ CABLES

MECHANICAL TEST DATA		
Test	Conditions	Result
Temperature Range	$-20^{o}C$ to $80^{o}C$	No attenuation change
Single 180^{o} Bend Radius:	≥ 2.54 cm	No attenuation change
Impact*	Hammer Diameter = 2.54 cm Impact level = .138m-kg (1ft-1b) 200 impacts @ $20^{o}C$ 100 impacts @ $71^{o}C$ 100 impacts @ $-54^{o}C$	No broken fibers
Twisting*	180^{o}/20cm twist Load = 2.3 kg 1000 cycles Temperature $-54^{o}C$ to $71^{o}C$	No broken fibers
Bending*	$\pm$ 90^{o} Bend, Load = 2.3 kg Mandrel Diameter / Temp. / Cycles 2.54cm / $20^{o}C$ / 10,000 3.18cm / $71^{o}C$ / 1,000 3.18cm / $-54^{o}C$ / 2,000	No broken fibers
Vibration**	Test Condition A, Method 204C	No broken fibers

ENVIRONMENTAL TEST DATA		
Test	Conditions	Result
Temperature** Cycling	$-55^{o}C$ to $85^{o}C$, 91 Kg load Test Condition A, Method 107D	No attenuation change after test. No change in tensile surviv-ability.
Moisture** Resistance	90% RH, 91 Kg load, Method 106 D, Step 7a for cold subcycle	No attenuation change after test. No change in tensile surviv-ability.
Radiation	Cumulative dose of 2300R (Co^{60} source) or 5.6×10^{11} neutrons/cm^2	$\leq$ 2dB/km attenuation increase between 0.8 and 0.9 nm†

*Tests carried out in accordance with MIL-C-13777F
**Tests carried out in accordance with MIL-STD-202E

† The attenuation increase is caused by colour centers arising from atomic or molecular changes in the glass lattice.

TABLE 3

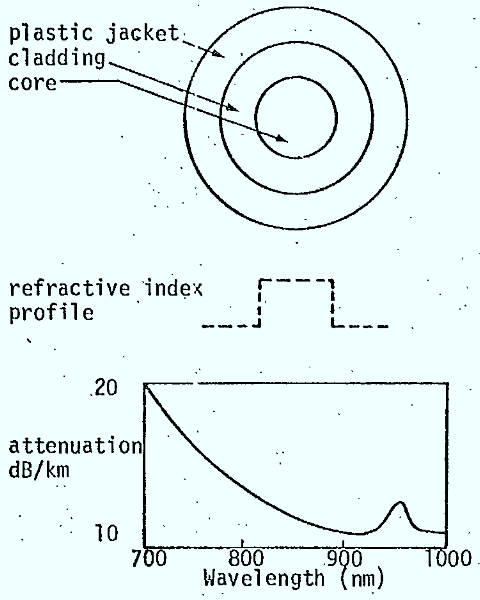
OPTICAL FIBER SPECIFICATIONS

Specifications for single strand optical-fiber waveguides with protective plastic coatings manufactured by Bell-Northern Research Ltd. (Canada) are listed.

PLASTIC COATED OPTICAL FIBERS - STEP INDEX

Tentative Specification BNR 7-1-A

These fibers are designed for use with high radiance LED's, lasers and silicon photo-detectors in medium bandwidth, single fiber channel optical communication systems. The fibers consist of a doped silica core surrounded by a doped silica cladding of lower refractive index. A plastic jacket is extruded onto the silica fiber to provide a non-fragile structure. The plastic coated fiber may be used directly in a benign environment. Alternatively, it is suitable for incorporation into multi-channel ruggedized cable formats. The fibers are designed to be compatible with high radiance LED's BNR 40-3-10-2, BNR 40-3-15-2, BNR 40-3-30-2, single optical fiber splices BNR S-10, single fiber bulkhead connectors BNR C-10 and small area silicon p-i-n photodetectors BNR D-5-1.



TYPICAL FIBER CHARACTERISTICS

	Nominal Value	Tolerance Maximum	Unit	Test Condition
Numerical Aperture (NA)	0.20	± 0.01		Fully filled NA; 5 meter length; 5% power points in far field pattern.
Attenuation (λ = 840 nm)	15		dB/km	Fully filled NA.
Bandwidth	20		MHz-km	
Core Outside Diameter (OD)	100	± 7	µm	
Cladding OD	150	± 7	µm	
Plastic Jacket OD	0.6	± 0.05	mm	
Tensile Strength	60	± 10	Newtons (kg m/sec^2)	60 cm test section
Bending Radius	3		mm	
Length	0.5		km	

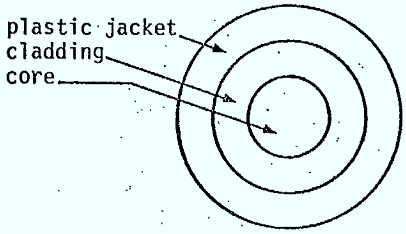
Quotations on fibers having longer lengths or characteristics other than those specified may be obtained on request.

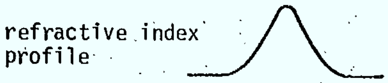
TABLE 3 (continued)

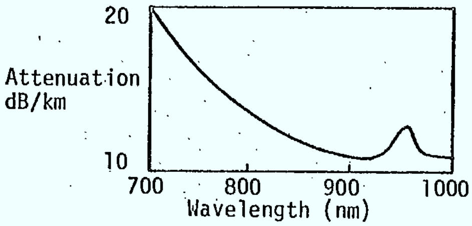
PLASTIC COATED OPTICAL FIBERS - GRADED INDEX

Tentative Specification BNR 7-2-A

These fibers are designed for use with high radiance LED's, lasers and silicon photodetectors in large bandwidth, single fiber channel optical communication systems. The fibers consist of a doped silica core with a graded refractive index, surrounded by a pure silica cladding. A plastic jacket is extruded onto the silica fiber to provide a non-fragile structure. The plastic coated fiber may be used directly in a benign environment. Alternatively, it is suitable for incorporation into multi-channel ruggedized cable formats. The fibers are designed to be compatible with high radiance LED's BNR 40-3-10-2, BNR 40-3-15-2, BNR 40-3-30-2, single optical fiber splices BNR S-10, single fiber bulkhead connectors BNR C-10 and small area silicon p-i-n photodetectors BNR D-5-1.







TYPICAL FIBER CHARACTERISTICS

	Nominal Value	Tolerance Maximum	Unit	Test Condition
Numerical Aperture (NA)	0.22	± 0.01		Fully filled NA; 5 meter length; 5% power points in far field pattern
Attenuation (λ = 840 nm)	15		dB/km	Fully filled NA
Bandwidth	100		MHz-km	
Core Outside Diameter (OD)	100	± 7	μm	
Cladding OD	150	± 7	μm	
Plastic Jacket OD	0.6	± 0.05	mm	
Tensile Strength	60	± 10	Newtons (kg m/sec^2)	60 cm test section
Bending Radius	3		mm	
Length	0.5		km	

Quotations on fibers having longer lengths or characteristics other than those specified may be obtained on request.

By the early 1980s, we can expect typical optical cable losses to be at approximately 4 dB/km while 2 dB/km cables may be available as "premium" cables. If -3 dBm (0.5 mW) of optical power is launched into a 2 dB/km loss fiber, for three TV channels in an FDM scheme, theoretical calculations show that a distance of more than 10 km can be spanned without a repeater and if three repeaters are used, more than 30 km can be covered. Such spans will be significant for application to rural cable television systems. Table 4 lists additional theoretical calculations for the transmission of 3 TV channels over a 2 dB/km loss fiber[10]. Similarly, Table 5 lists theoretical calculations for transmission of baseband TV signals over a 2 dB/km loss fiber[11]. Approximate distances for the case of a 4 dB/km loss fiber can be obtained by dividing the values in the two tables by 2.

4.2 Optical-Fiber Couplers

Table 6 shows specifications for optical fiber couplers and splices that are commercially available now. Typical insertion losses can be lower than 0.5 dB. Some other firms are offering different designs in optical fiber couplers[12],[13] and we can expect the designs to become standardized in the future.

4.3 Light Sources

For analogue IM optical transmission systems, a light source with linear response (drive current vs. light output power) characteristics is required. Otherwise, intermodulation distortion noise will severely degrade the transmitted video signal. We have determined that a light emitting diode (LED) manufactured by Bell-Northern Research Ltd. (BNR) has sufficient linearity to use in an FDM analogue transmission system[14] similar to those discussed here.

TABLE 4

OPTICAL ANALOGUE TRANSMISSION OF 3 TV CHANNELS USING AN FDM SCHEME

Distances are listed as a function of the number of repeaters. The use of an APD with $R_L = 10\ k\Omega$ and a coupler loss of 0.5 dB/coupler (2 couplers/repeater) is assumed.

Total power launched into fiber	0 dBm (1 mW)		-3 dBm (0.50 mW)		-5 dBm (0.34 mW)	
Optical fiber loss	2 dB/km		2 dB/km		2 dB/km	
Number of repeaters	Separation Distance (km)	Total Distance (km)	Separation Distance (km)	Total Distance (km)	Separation Distance (km)	Total Distance (km)
0	11.8	11.8	10.3	10.3	9.35	9.35
1	10.6	21.2	9.10	18.2	8.10	16.2
2	9.85	29.6	8.35	25.1	7.35	22.1
3	9.35	37.4	7.85	31.4	6.85	27.4
4	8.90	44.5	7.40	37.0	6.40	32.0
5	8.60	51.6	7.10	42.6	6.10	36.6
6	8.35	58.5	6.85	48.0	5.85	41.0
7	8.10	64.8	6.60	52.8	5.60	44.8
8	7.85	70.7	6.35	57.2	5.35	48.2
9	7.65	76.5	6.15	61.5	5.15	51.5

TABLE 5

OPTICAL ANALOGUE TRANSMISSION OF BASEBAND VIDEO SIGNALS

Distances are listed as a function of the number of repeaters. The use of an APD with R_L = 100 kΩ and a coupler loss of 0.5 dB/km coupler (2 couplers/repeater) is assumed.

Power launched into fiber	0 dBm (1 mW)		-3 dBm (0.50 mW)		-5 dBm (0.32 mW)	
Optical fiber loss	2 dB/km		2 dB/km		2 dB/km	
Number of Repeaters	Separation Distance (km)	Total Distance (km)	Separation Distance (km)	Total Distance (km)	Separation Distance (km)	Total Distance (km)
0	16.6	16.6	15.1	15.1	14.1	14.1
1	15.3	30.6	13.8	27.6	12.8	25.6
2	14.6	43.8	13.1	39.3	12.1	36.3
3	14.1	56.4	12.6	50.4	11.6	46.4
4	13.7	68.5	12.2	61.0	11.2	56.0
5	13.3	79.8	11.8	70.8	10.8	64.8
6	13.1	91.7	11.6	81.2	10.6	74.2
7	12.8	102.	11.3	90.4	10.3	82.4
8	12.6	113.	11.1	99.9	10.1	90.9
9	12.5	125.	11.0	110.	10.0	100.

TABLE 6

SPECIFICATIONS FOR AN OPTICA-FIBER SPLICE AND COUPLER

Specifications for an optical-fiber splice and coupler manufactured by Bell-Northern Research Ltd. (Canada) are listed.

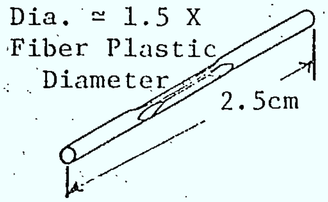
SINGLE OPTICAL FIBER SPLICE

Tentative Specification BNR S-10

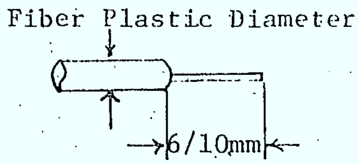
The splicing element is used to make a permanent, high efficiency fiber-to-fiber connection on individual, plastic-coated, multimode fibers. The splicing element which is formed from stainless steel tubing, is approximately 2.5 cm in length. The diameter of the completed splice is slightly larger than the diameter of the plastic-coated fiber (typically, 1.5 mm for a fiber with a plastic jacket diameter of 0.9 mm).

For high efficiency the splicing element is prefilled with an index matching fluid.

SPLICING ELEMENT



PREPARED FIBER END



INSTALLATION

Prior to insertion in the splicing element, the plastic coating is removed from the fiber ends. Each end is then prepared to have a smooth, flat, end surface which is perpendicular to the fiber axis.

The prepared fiber ends are inserted in the splicing element and butted end-to-end in the preformed center section. The ends of the splicing element are then crimped into the fiber's plastic coating, to make a permanent connection.

Laboratory tooling and techniques are available at BNR for preparing the fiber ends, to insert the fibers in the splicing element and to crimp the splicing element onto the fiber.

PERFORMANCE

Fiber Parameters Core Diameter	N.A.	Index Matching Fluid	Typical Efficiency (Insertion Loss)
125 μm	0.64	Dow Corning 710	93% (0.3 dB)
100 μm	0.20	Dow Corning 710	85% (0.7 dB)

Splicing elements can be made to accommodate the following typical fiber geometries:

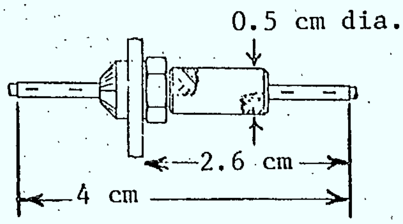
Plastic Coating Diameter	0.5 mm to 1.5 mm
Bare Fiber Diameter	100 μm to 175 μm

TABLE 6 (continued)

A SINGLE-FIBER BULKHEAD CONNECTOR

Tentative Specification BNR C-10

The single-fiber bulkhead connector is designed to be used with plastic-coated, multimode fibers. It is installed in optical fiber links wherever there is a need to make and break the fiber continuity quickly and reliably. The connector housing and internal parts are made of stainless steel.



For high efficiency, the connector is prefilled with an index matching fluid.

INSTALLATION

Prior to insertion in the connector, the plastic coating is removed from the fiber ends. Each end is then prepared to have a smooth, flat, end surface which is perpendicular to the fiber axis.

The connector halves are mounted separately on an installation fixture. The prepared fibers are inserted into the connector halves until they butt against stops in the installation fixture. The stops control the end-to-end positioning of the fibers and ensure that the connectors are interchangeable. The ends of the connector halves are then crimped into the fiber's plastic coating producing a permanent attachment.

Laboratory tooling and techniques are available at BNR to prepare the fiber ends and to install the fibers in the connector.

PERFORMANCE

Fiber Parameters Core Diameter	N.A.	Index Matching Fluid	Typical Efficiency (Insertion Loss)
125 μm	0.64	Dow Corning 710	90% (0.5 dB)
125 μm	0.64	None	77% (1.1 dB)
100 μm	0.20	Dow Corning 710	81% (0.9 dB)
100 μm	0.20	None	70% (1.5 dB)

Connectors can be made to accommodate the following typical fiber geometries:

Plastic Coating Diameter	0.5 mm to 1.5 mm
Bare Fiber Diameter	100 μm to 175 μm

The design concept for the single-fiber connector is readily adaptable to multi-fiber connectors suitable for the simultaneous and independent connection of the fibers in a multifiber cable.

Although the optical output power launched by the LED into a typical optical fiber is less than -5 dBm (0.35 μW), we expect that -3 dBm (0.5 μW) can be achieved with little trouble in the future. In many applications, -3 dBm is sufficient power, but 0 dBm (1 mW) or higher levels will certainly increase the repeater-less transmission distance. Edge-emitter type LEDs may achieve this level[†] and our preliminary investigation of CW double heterostructure semiconductor laser diodes indicate that laser diodes may have sufficient linearity if the oscillation modes can be controlled suitably[††]. We can expect laser diodes to launch in excess of several milliwatts into typical fibers.

A recent report indicates that the efficiency of LEDs can be improved by an order of magnitude through the use of a specific manufacturing process to control the distribution of point-defects (vacancy and interstitial) within the LED[(15)]. If the technique proves effective, more than 0 dBm can be launched into a fiber from an LED. It remains to be seen what influences the improved efficiency has on the linearity of the LED.

The cost of LEDs and laser diodes suitable for optical communications at present range from $200 to over $1000 each. These costs are expected to be reduced by more than an order of magnitude once mass production is started.

4.4 Photodetectors

Photodetectors are perhaps the most developed among the opto-electronic components for optical communications. There is a wide choice of commercial products and some typical examples are listed in Table 7. Current costs are also listed in the table. The cost of APDs are expected to become comparable to PIN diodes if mass production is started. Some manufacturers such as Bell-Northern Research Ltd. supply diodes with an optical-fiber permanently attached for direct connection to a fiber transmission line. The linearity of response (optical input power vs.

† Laser Diode Laboratories Inc. is offering an edge-emitting LED that provides 1.5 mW output power at 100 mA drive current (Laser Focus, December 1976, pp. 44-45).

†† Oscillation modes can be controlled by confining the lasing volume to a small size (e.g. 1 μm x 1 μm cross-section) by using a distributed feedback structure. Both approaches have been successfully employed in laboratory devices.

TABLE 7

SILICON PHOTODETECTOR CHARACTERISTICS

Type	Spectral Peak (nm)	Bias Voltage (v)	Resposivity (MA/μW)	Capacitance (pF)	Rise Time (ns)	Dark Current (nA)	NEP ($w/\sqrt{HZ}$)	Approximate Cost $
RCA C 30817 (APD)	910	335	80	2	2	100	10^{-14}	200
EMI S 30500 (APD)	880	166	37	5.5	0.5	0.1	$9x10^{-13}$	200
RCA C 30808 (PIN Diode)	910	45	0.65	6	5	30	$2x10^{-13}$	15
UDT PIN-5D (PIN Diode)	850	50	0.40	7	15	100	$5x10^{-13}$	20

electrical output power) has been found to be excellent for some commercial samples[16] in comparison to the linearity of LEDs. Little problem therefore is expected from photodiodes.

4.5 Switching Systems

There are a number of computer controlled switching systems for telephone exchanges. The "Touch-Tone" switching matrix shown in Fig. 3 can be constructed by using commercial diode switches such as AM1002 manufactured by National Semiconductor Corp. (NS) (USA). Private branch exchanges (PBX) using microprocessors and all-solid-state construction are available from companies such as Mitel Ltd. (Ottawa) and Northern-Telecomm (Montreal). The switching matrix of such PBXs can be adapted for use in the "Touch-Tone" switching matrix. The CPU or microprocessor units (MPU) used in these PBXs can also be adapted or expanded to be used in the system described in Fig. 3.

For the TV switching matrix, no commercial product is available at the moment. However, solid state switches such as the AM1002 might be used to construct a CPU controlled switching matrix. The specifications for AM1002 (NS) are shown in Table 8. The isolation at 5 MHz is said to be approximately 60 dB[17]. A problem with video switches is the requirement of high isolation in order to prevent leakage of TV channels through the switch.

According to design objectives set by Nippon Telegraph and Telephone (NTT) Public Corporation of Japan, an isolation of 71 dB at 4 MHz is demanded for baseband video switching. The eventual intended application by NTT of such switches is to a fully switched video-telephone network. Laboratory devices have achieved isolation of 65 dB and the target of 71 dB is considered practical by NTT[18]. For the type of one-way distribution of TV signal discussed in this memorandum, isolation of 71 dB may not be required and the 60 dB isolation offered by AM1000 may be sufficient.

TABLE 8

SPECIFICATIONS OF AN ANALOGUE SWITCH

Specifications of the semiconductor analogue switches AM1000, AM1001 and AM1002 manufactured by National Semiconductor Corp. (USA) are listed.

AM1000,AM1001,AM1002 silicon N-channel high speed analog switch

general description

The AM1000 series are junction FET integrated circuit analog switches. These devices commutate faster and with less voltage spiking than any other analog switch presently available. By comparison, discrete JFET switches require elaborate drive circuits to obtain reasonable performance for high toggle rates. Encapsulated in a four pin TO-72 package, these units require a minimum of circuit board area. Switching transients are greatly reduced by a monolithic integrated circuit process. The resulting analog switch device provides the following features:

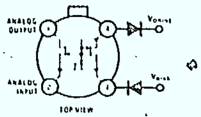
- Low ON Resistance 30Ω
- High Analog Signal Frequency 100 MHz
- High Toggle Rate 4 MHz
- Low Leakage Current 250 pA
- Large Analog Signal Swing ±15V
- Break Before Make Action

The AM1000 series of analog switches are particularly suitable for the following applications:

- High Speed Commutators
- Multiplexers
- Sample and Hold Circuits
- Reset Switching
- Video Switching

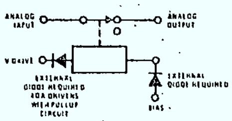
schematic and connection diagram

TO-72 Package



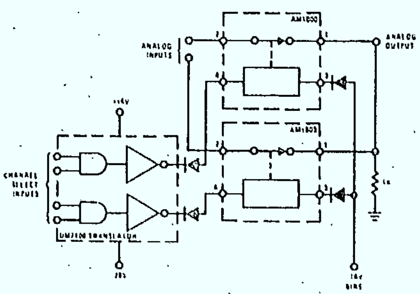
Order Number AM1000H
or AM1001H or AM1002H
See Package 9A

equivalent circuit



typical applications

±10 Volt Swing Analog Switch 0.5% Accuracy



±15 Volt Swing Analog Switch

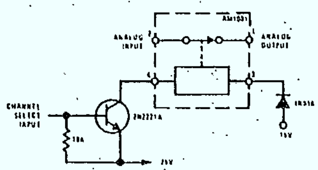


TABLE 8 (continued)

absolute maximum ratings

	AM1001	AM1000 AM1002
V_{IN} (Note 1)	+50V	+40V
V_{OUT} (Note 1)	+50V	+40V
V_{DRIVE} (Note 1)	−50V	−40V
V_{BIAS} (Note 1)	+50V	+40V

Power Dissipation @ T_A = 25°C	300 mW
Linear Derating Factor	1.7 mW/°C
Power Dissipation @ T_C = 125°C	150 mW
Linear Derating Factor	6 mW/°C
Maximum Junction Operating Temperature	−55°C to +150°C
Storage Temperature	+200°C
Lead Temperature (Soldering, 10 sec)	+300°C

electrical characteristics

ON CHARACTERISTICS (Note 2)

PARAMETER	CONDITION		MIN	TYP	MAX	UNITS
R_{ON}	V_{DRIVE} = +15V, V_{BIAS} = −15V I_{IN} = 1 mA, V_{OUT} = 0V	AM1001	20	40	50	Ω
R_{ON}	V_{DRIVE} = +10V, V_{BIAS} = −10V I_{IN} = 1 mA, V_{OUT} = 0V	AM1000	20	25	30	Ω
		AM1002	20	50	100	Ω

OFF CHARACTERISTICS

PARAMETER	CONDITION	AM1000 AM1001			AM1002			UNITS
		MIN	TYP	MAX	MIN	TYP	MAX	
$I_{OUT(OFF)}$	V_{DRIVE} = −20V, V_{BIAS} = −10V V_{IN} = 10V, V_{OUT} = +10V							
	T_A = +25°C		.05	.25		0.5	1	nA
	T_A = +125°C		.025	.25		0.2	1	μA
$I_{OUT(OFF)}$	V_{DRIVE} = −20V, V_{BIAS} = −10V V_{IN} = +10V, V_{OUT} = −10V							
	T_A = +25°C		.05	.25		0.5	1	nA
	T_A = +125°C		.05	.25		0.2	1	μA

DRIVE CHARACTERISTICS (Note 1)

PARAMETER	CONDITION	MIN	TYP	MAX	UNITS
I_{DRIVE} (Switch OFF)	V_{DRIVE} = 20V, V_{BIAS} = −10V AM1000, 1001, 1002 V_{IN} = ±10V, V_{OUT} = ±10V		5	10	mA

SWITCHING CHARACTERISTICS

PARAMETER	CONDITION	AM1000 MAX	AM1001 MAX	AM1002 MAX	UNITS
t_{ON}	See Switching Time Test Circuit	100	150	200	ns
t_{OFF}		100	100	100	ns

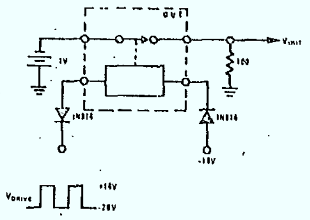
Note 1: The maximum voltage ratings may be applied between any pin or pair simultaneously. Power dissipation may be exceeded in some modes if the voltage pulse exceeds 10 ms. Normal operation will not cause excessive power dissipation even in a "D.C." switching application.

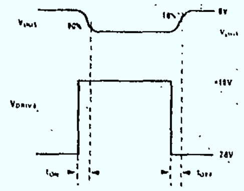
Note 2: All parameters are measured with external silicon diodes. See electrical connection diagram for proper diode placement.

Note 3: I_{BIAS} (Switch OFF) is equal to I_{DRIVE} (Switch OFF). $I_{(BIAS)}$ (Switch ON), is equal to external diode leakage.

Note 4: Rise and fall times of V_{DRIVE} shall be 15 ns maximum for switching time testing.

switching time test circuit and waveforms





Aside from the problem of signal isolation in the solid state switch, another equally serious problem is the isolation between the lead wires connecting the TV signals to the switch. Even if the switch itself offers sufficient isolation, depending on the layout of the circuit, leakage levels strong enough to degrade a TV signal can occur. The problem is more serious for printed circuit boards where the compact layout of leads to the switches provides ample opportunity for coupling between leads. If subcarrier frequencies are to be switched, the isolation by the solid state switch will degrade at the higher frequencies and coupling between the leads will also increase. Further development work is required in the area of the TV switching matrix. Switching in the optical domain, rather than in the RF domain can be considered. For example, electro-mechanical switching by moving optical waveguides has the potential to provide perfect isolation.

4.6 Electronic Circuitry

Much of the electronic circuitry for optical communications is under development at various laboratories. Some conceptual circuits as well as practical circuits have already been published[19]. Appendices A, B, C, D, E and F contain a collection of typical circuit configurations that may be modified to fit most requirements described in this memorandum. Further development work is required in this area to bring the circuitry to a commercially useful stage.

5. DISCUSSION

In view of the distances that can be covered by low-loss optical-fiber transmission systems, a centrally switched optical television distribution system may well be attractive for application not only to urban areas, but also to rural areas. Different grades of fibers can be used appropriately for short urban lines and extended rural lines.

When required, repeater amplifiers can be used in the rural lines. By integrating the telephone system into the distribution system, some advantage in economics may be gained as well. Such an integration will require extensive reorganization of the Canadian communications structure.

The interconnection of central switching offices can also be performed by optical fibers. Depending on the transmission distance, digital transmission modes may need to be employed. If a video-bandwidth switching matrix with sufficient isolation is developed, a switched broadband (video-telephone) network can be established.

The optical communications technology today has developed to a level where it can supply components for the construction of an experimental system to investigate the optimum network and circuit configurations. An experimental trial in the laboratory most likely will be required first to assess the performance of various system components. A field trial involving 100 subscribers or so could then determine whether expectations based on laboratory experiments can be realized.

The cost of experimental systems will necessarily be high for the trials because many components are still under development and no industrial standards have been established. However, field trials should clarify the cost of future commercial systems.

6. ACKNOWLEDGEMENTS

I would like to thank K.O. Hill for suggesting the work in this area. Discussions with H. Claire Frayn and V.A. Goodman are gratefully acknowledged. I would also like to thank Mitel Ltd. for providing information on switching matrices.

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22. ibid., pp. 10, 12.

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APPENDIX A

DRIVER CIRCUITS FOR SEMICONDUCTOR LIGHT SOURCES

Figure A-1 shows the circuit used in the analogue video transmitter manufactured by Bell-Northern Research Ltd. Specifications of a wideband optical link using the unit are listed in Table A-1. Visually satisfactory baseband signals have been transmitted over a fiber using the unit.

Figure A-2 shows a circuit similar to that of the BNR unit. The design has been in use at the Communications Research Centre as part of a demonstrator optical video link for many years†. The light source is a single heterostructure laser diode excited below lasing threshold. In effect, the diode is being used as an edge-emitting LED. Because of the small size of the diode, in comparison to standard LEDs for display purposes, coupling into a bundle of fibers was found to be excellent. Visually satisfactory baseband video signals are transmitted by this design.

Conventional RF power amplifiers may also be used to drive semiconductor light sources. Figure A-3 shows a circuit used to transmit simultaneously 2 TV channels using an FDM scheme[20]. Frequency allocations for the subcarriers were 25 MHz and 31 MHz. Integrated circuit power amplifiers with a frequency range from DC to 6 MHz may also be used in a similar circuit to transmit baseband video channels.

The linearity of the light-source current versus optical output power may be a limiting factor in the performance of a FDM video transmission system. Figure A-4 shows an example using negative feedback to improve the linearity. A matched pair of LEDs is required in this design. By using a matched pair, the optical output power from the transmitting LED need not be sacrificed to provide the feedback signal.

---

† Designer of the circuit is H. Claire Frayn.

However, the optimum degree of improvement achievable will be degraded if the 2 LEDs are not well matched in terms of current versus optical output power. If a laser diode is used as the light source, the optical output from the rear edge of the laser chip may be coupled directly to the APD and a matched pair will not be required.

The stability of the feedback loop will depend on the loop gain and degree of phase shift within the loop. If difficulty is encountered other types of integrated circuit (IC) video amplifiers such as SN52733 and SN5510 manufactured by Texas Instruments Inc. should be considered.

Detailed evaluations of the circuits discussed here have not been performed yet.

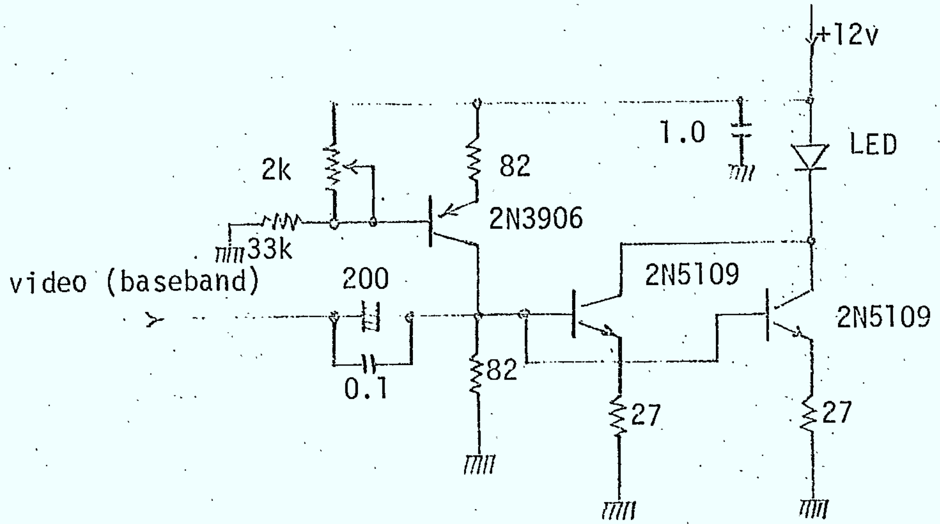


Fig. A-1 CIRCUIT FOR THE ANALOGUE OPTICAL VIDEO TRANSMITTER MANUFACTURED BY BELL-NORTHERN RESEARCH LTD.

Two transistors are connected in parallel to provide sufficient drive current through the LED.

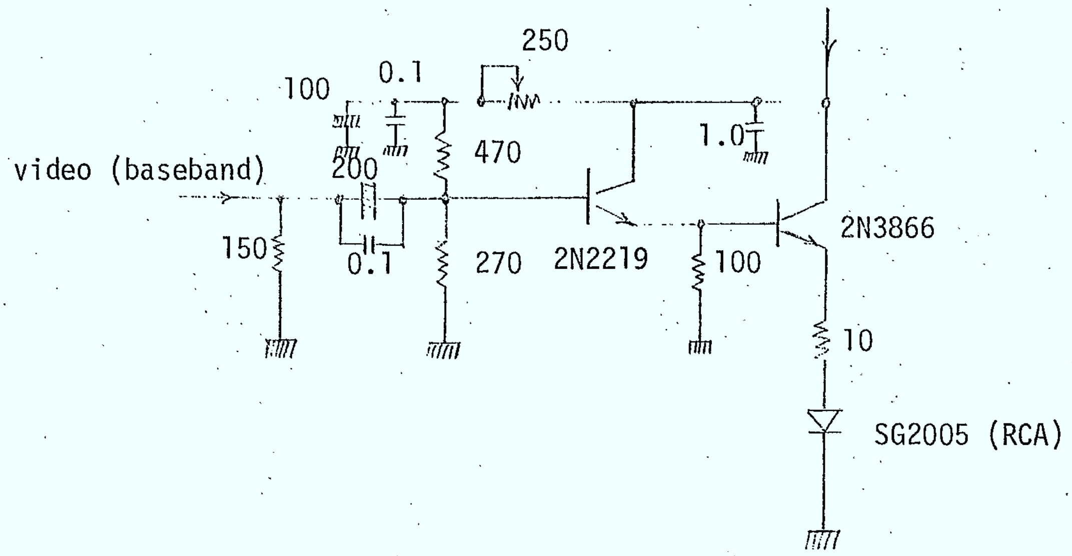


Fig. A-2 ANALOGUE OPTICAL VIDEO TRANSMITTER CIRCUIT IN USE AT CRC

A single heterostructure laser diode (RCA SG2005) is excited below threshold.

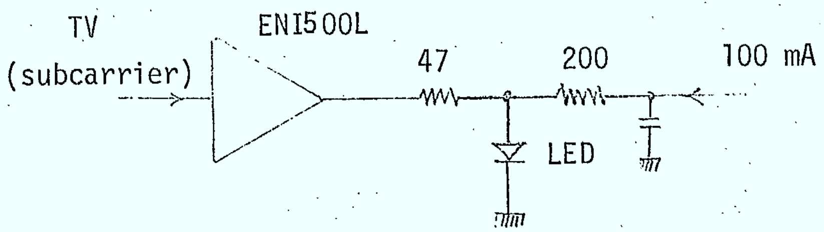
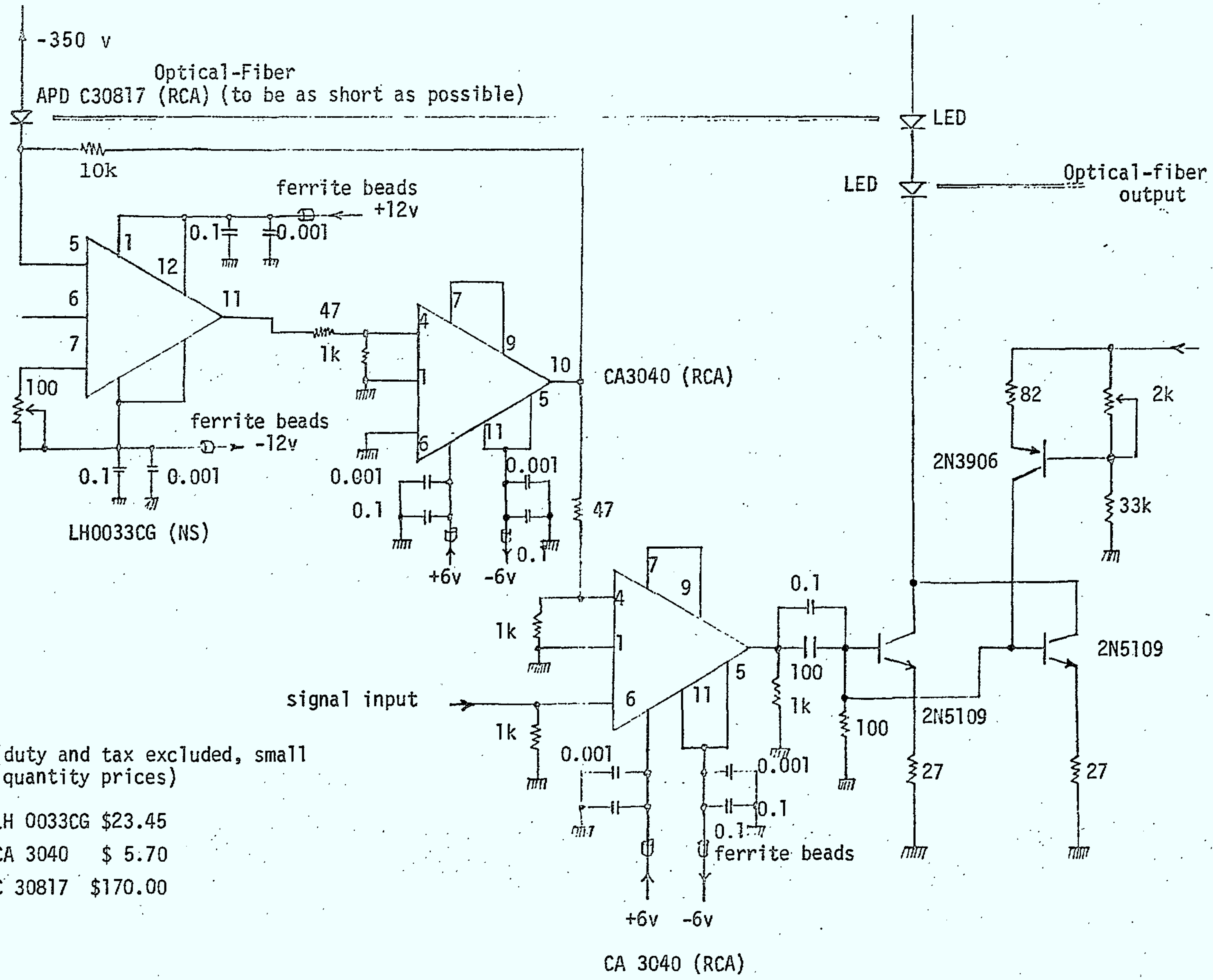


Fig. A-3 FDM ANALOGUE OPTICAL VIDEO TRANSMISSION EXPERIMENT

A commercial RF amplifier is used to modulate the LED with the subcarrier frequencies. The amplifier has 20 dB voltage gain with 50 input and output impedances. A maximum of 250 mW can be delivered with a frequency response of 5 MHz to 250 MHz.



Costs (duty and tax excluded, small quantity prices)

LH 0033CG	$23.45
CA 3040	$ 5.70
C 30817	$170.00

Fig. A-4 LINEARIZATION OF AN LED WITH NEGATIVE FEEDBACK

Matched pairs of LEDs together with an APD are used to provide a large open loop gain.

TABLE A-1

ANALOGUE OPTICAL VIDEO LINK

Specifications of a wideband analogue optical link manufactured by Bell-Northern Research Ltd. (Canada) are listed.

Typical Performance

These single-fiber/channel optical links are suitable for the construction of high performance analog transmission facilities. The links eliminate ground loop problems, crosstalk, EMI, line surge produced circuit failures, reduce signal distortion and allow long transmission path lengths.

The optical interconnection is via single-fiber bulkhead connectors, BNR C-10. For the transmission medium any connector-compatible, plastic-coated multimode fiber, such as BNR 7-1-A step-index fiber or BNR 7-2-A graded-index fiber, can be used.

N.B. Systems based on these components to provide switched, multiplexed or integrated service transmission of studio quality video, high speed data and high fidelity voice can be designed to meet specific requirements.

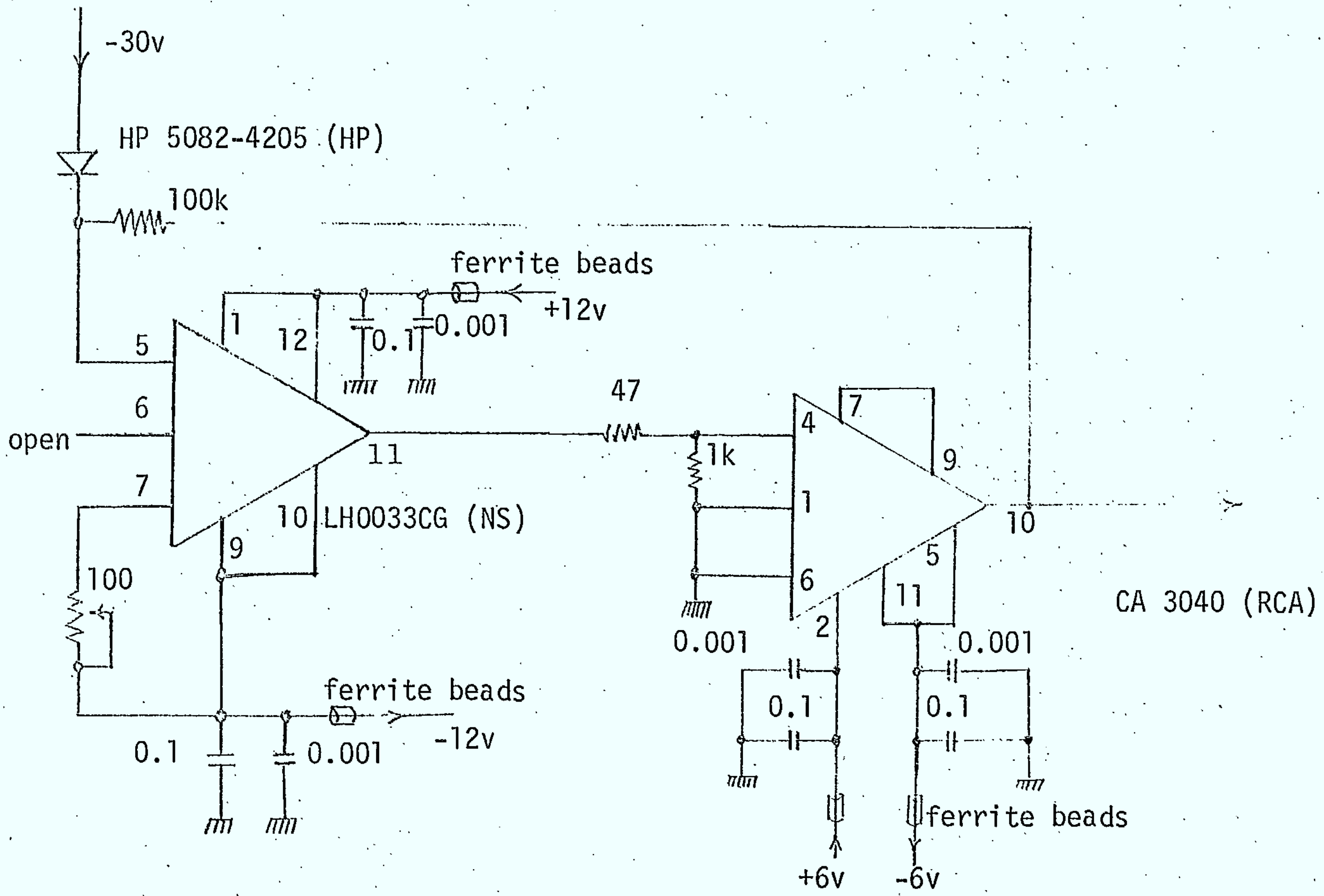
Link Performance	
Bandwidth (3 dB)	10 HZ - 20 MHz
Optical Gain	25 dB max
S/N ratio (4.5 MHz bandwidth)	55 dB @ 25 dB optical loss
Distortion (Baseband video)	0.1 dB diff. gain, 0.1° diff. phase (@ max. optical gain)
Transmitter Characteristics	
Input Impedance	75 Ω
Maximum Input	1 V RMS
Optical Output	Adjustable
Power Supply Requirement	+ 12 V DC @ 200 mA (internally decoupled)
Electrical Input Connector	BNC or SMA
Optical Input Connector	Single-Fiber Bulkhead Connector, BNR C-10
Receiver Characteristics	
Output Impedance	5 Ω
Gain	Adjustable
Power Supply Requirements	+ 12 V DC @ 100 mA (internally decoupled)
Dimensions	5 cm x 5cm x 2cm
Electrical Output Connector	BNC or SMA
Optical Input Connector	Single-Fiber Bulkhead Connector, BNR C-10

APPENDIX B

CONCEPTUAL DESIGN OF A PHOTODETECTOR CIRCUIT

Figure B-1 shows a circuit design that may be used for a photodetector. A voltage follower with high input impedance allows the use of a high load resistor (R_L) without a reduction in frequency response because the input becomes a virtual ground due to the feedback through the load resistor. A high load resistor improves the signal to noise ratio and provides a larger output voltage[21].

The first integrated circuit (IC) is an impedance transformer. Input impedance of the LH 0033CG (National Semiconductor Corp.) is well in excess of 10 MΩ while the output impedance is less than 50 Ω. A relatively high voltage is required for the PIN photodiode in order to assure a linear operation. The CA3040 (RCA) has a gain of approximately 30 dB. Experimental work is needed to assure that the phase shift within the feedback loop is not excessive so as to make the circuit unstable. An avalanche photodiode (APD) such as C 30817 (RCA) may be used in place of the HP 5082-4205 (Hewlett-Packard) PIN photodiode. An APD will provide higher gain and a slightly better signal to noise ratio[22].



Costs (duty and tax excluded, small quantity prices)

HP 5082-4205	\$22.99
LH 0033CG	\$23.45
CA 3040	\$5.70

Fig. B-1 PHOTODETECTION CIRCUIT

At present operational amplifiers with high input impedance ($\sim 1 M\Omega$) and amplification bandwidth extending beyond 30 MHz are not commercially available. A hybrid IC voltage follower is therefore used in the input circuitry.

APPENDIX C

MODULATOR AND DEMODULATOR CIRCUITS FOR TRANSMISSION OF TV CHANNEL-SELECTION TONE-SIGNALS

Figure C-1 shows an FM circuit for the tone signals used for TV channel selection. The subcarrier frequency can be chosen suitably by taking into consideration the intermodulation noise that may be produced by two such circuits. Figure C-2 shows the demodulator circuit based on a phase-locked loop design (PLL). Other PLL IC devices such as XR 215 by Exar Integrated Systems of R-Ohm Corp. may also be used to demodulate the signal.

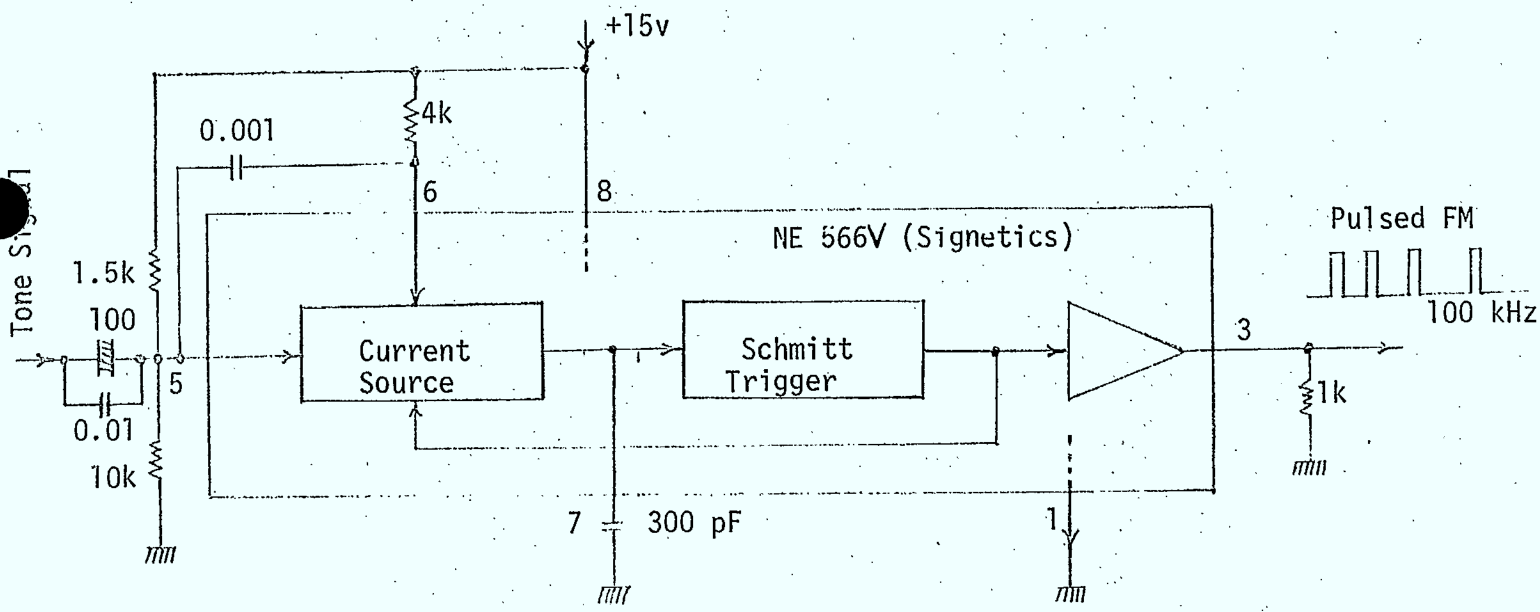


Fig. C-1 PULSED FM CIRCUIT FOR TRANSMISSION OF TV CHANNEL-SELECTION TONE-SIGNALS

A voltage controlled oscillator (VCO) NE 566V by Signetics Corp. is used to produce the pulsed FM signal.

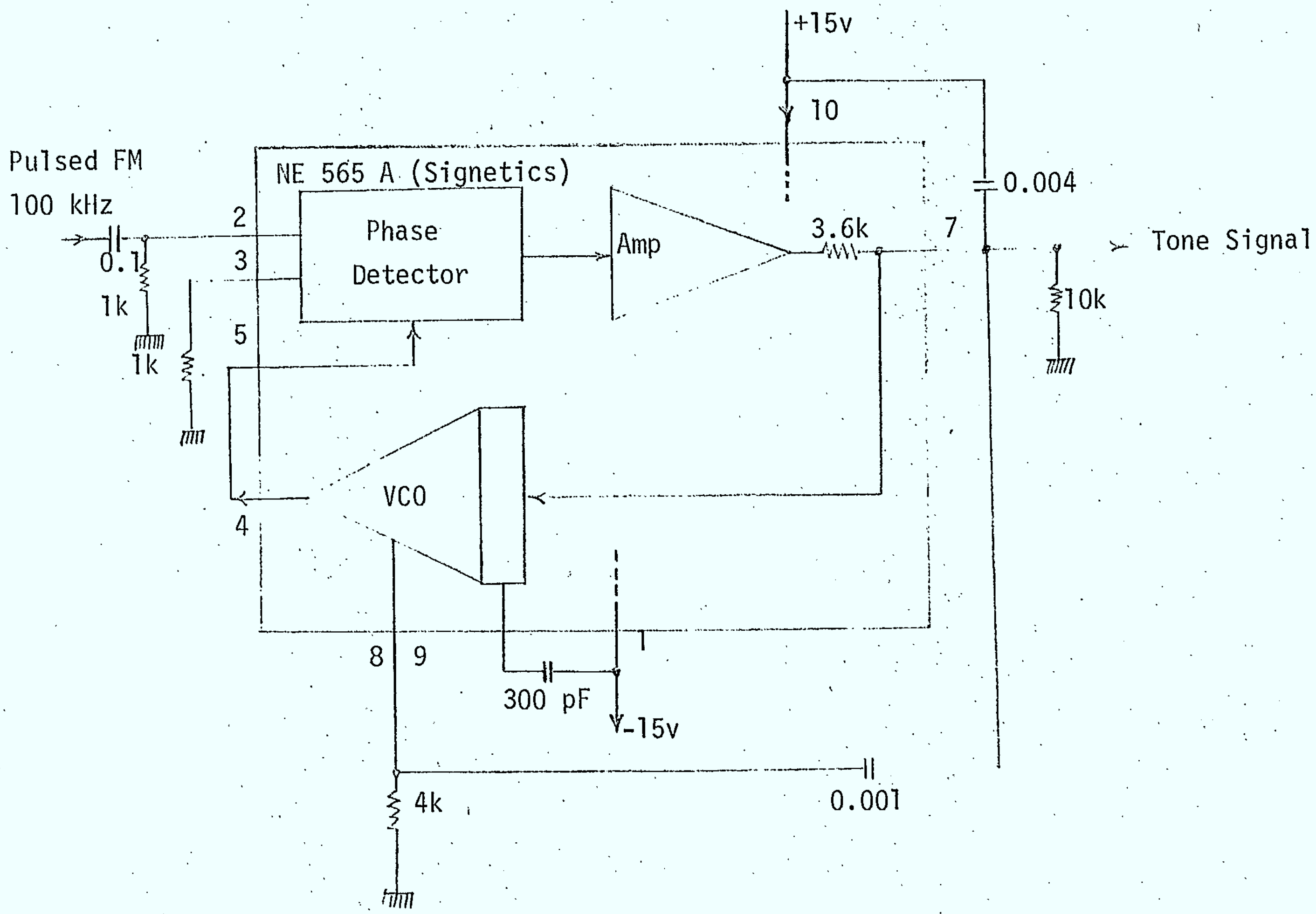


Fig. C-2 DEMODULATOR CIRCUIT FOR PULSED FM SIGNALS

A phase lock loop IC unit NE 565A by Signetics Corp. is used to demodulate the pulsed FM signal and reproduce the TV channel-selection tone-signals.

APPENDIX D

CONCEPTUAL DESIGN OF A MODULATION CIRCUIT FOR FDM TV TRANSMISSION

Figure D-1 shows a conceptual design of a modulation circuit for FDM TV transmission. The subcarrier frequency (13 MHz or 19 MHz) is provided by a common source through a voltage follower LM0033CG manufactured by National Semiconductor Corp. The follower has a low output impedance (6 Ω) and a high output current (250 mA), and is capable of supplying a signal to a large number of current amplifiers such as the LM0002C manufactured by National Semiconductor Corp.

Modulation of the subcarrier is performed by a double-balanced mixer. The subcarrier frequency and TV signal (baseband video and 4.5 MHz FM audio) are mixed and the products are filtered by the vestigial sideband filter to produce an NTSC TV signal. Experimental work will be needed to determine whether Broadcast Procedure 23 (BP-23) standards can be met by the circuit.

Costs (duty and tax excluded,
small quantity prices)

LM 0002 C	$9.40
MD 108	$7.00
VS Filter	$100.00 (estimated)

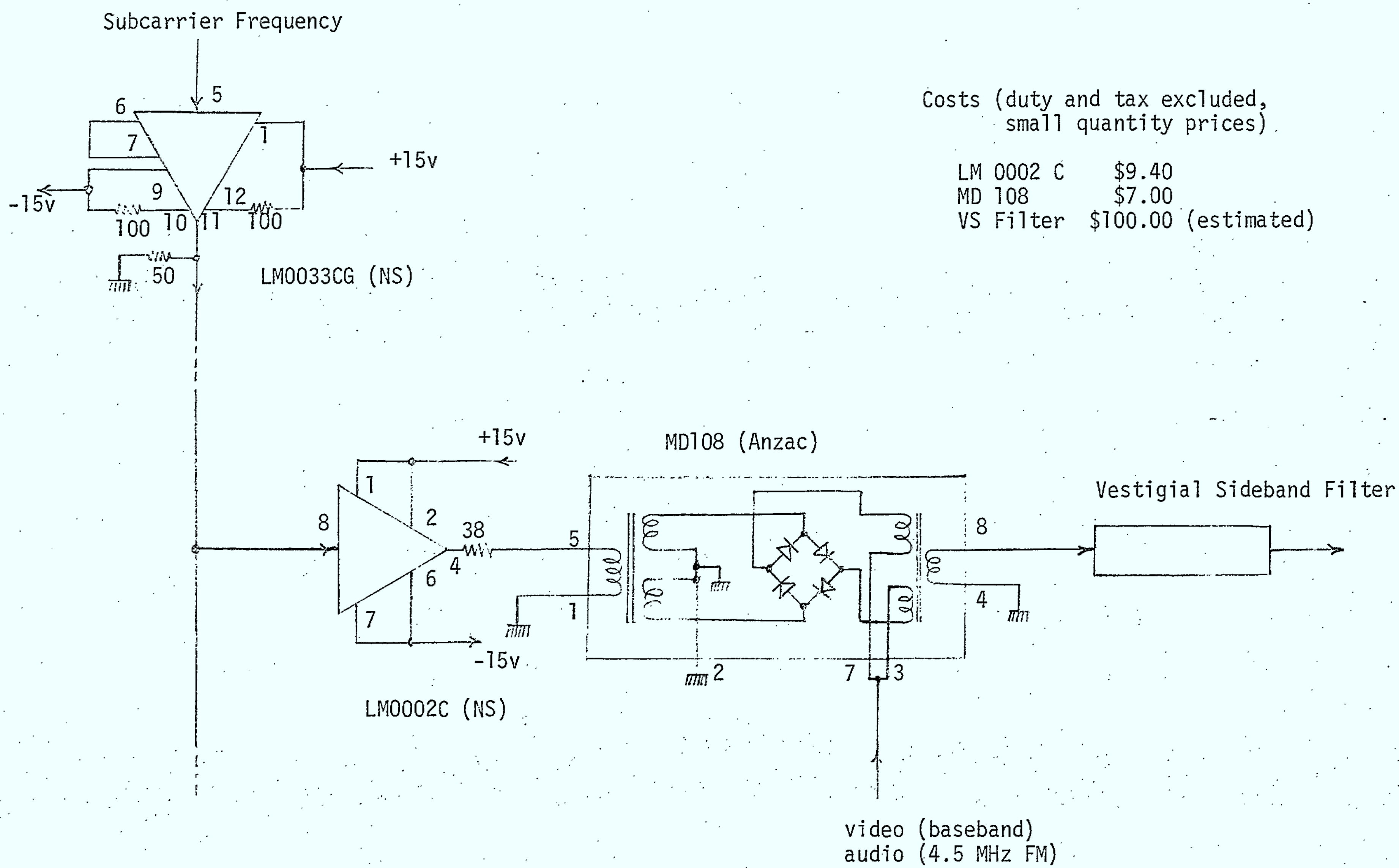


Fig. D-1 MODULATION CIRCUIT FOR FDM TV TRANSMISSION

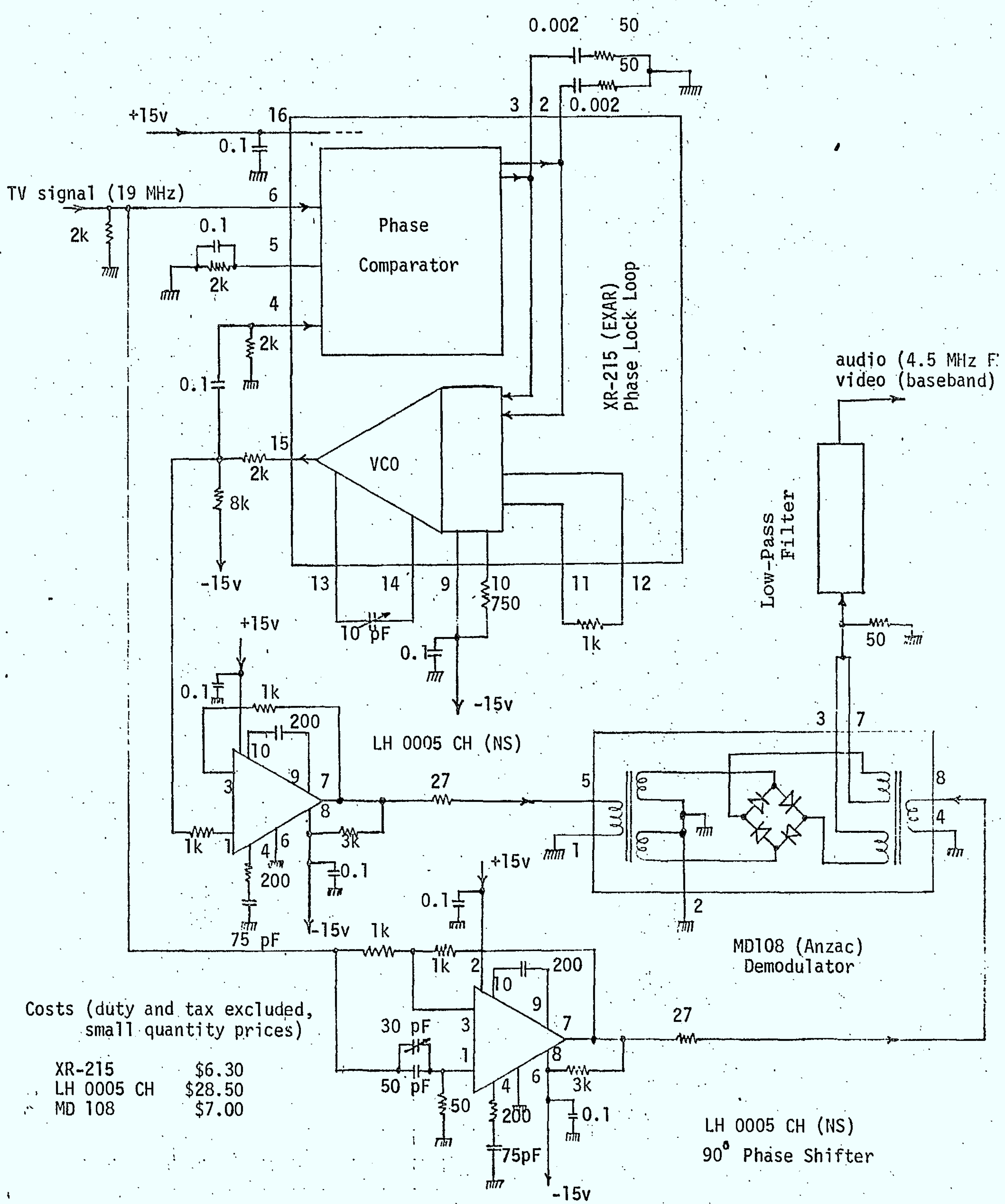
A double-balanced modulator is used to mix the subcarrier frequency and the TV signal (baseband video and 4.5 MHz FM audio).

APPENDIX E

CONCEPTUAL DESIGN OF A COHERENT DEMODULATOR FOR A TV SIGNAL ON A SUBCARRIER FREQUENCY

Figure E-1 shows a conceptual design of a demodulator circuit for obtaining a TV signal (baseband video and 4.5 MHz FM audio) from the subcarrier frequencies (13 MHz or 19 MHz). A phase lock loop (PLL) XR-215 manufactured by the Exar Integrated Systems of R-Ohm Corp. is used to reproduce the subcarrier frequency with the voltage controlled oscillator (VCO). The output of the VCO is supplied as the reference frequency to the double-balanced mixer MD-108 manufactured by Anzac Electronics through an operational amplifier LH0005CH manufactured by National Semiconductor Corp. The amplifier is operated at unity gain as a buffer. The TV signal is 90° phase shifted through a phase shifting circuit which uses an LH0005CH and then supplied to the demodulator. Since the reference frequency and the TV signal are 90° out-of-phase, the mixer acts as a coherent (homodyne) detector and amplitude demodulation takes place. The output of the demodulator is passed through a low-pass filter to recover the baseband video and 4.5 MHz FM audio signals. Experimental work will be needed to evaluate the performance of this circuit.

The circuit functions of Fig. E-1 can be integrated into a single IC configuration. The NE561B manufactured by Signetics Corp. is such an IC and Fig. E-2 shows a conceptual design which should function satisfactorily[23]. The use of ICs such as the NE561B will simplify the design of TV receivers for centrally switched optical TV-distribution systems.

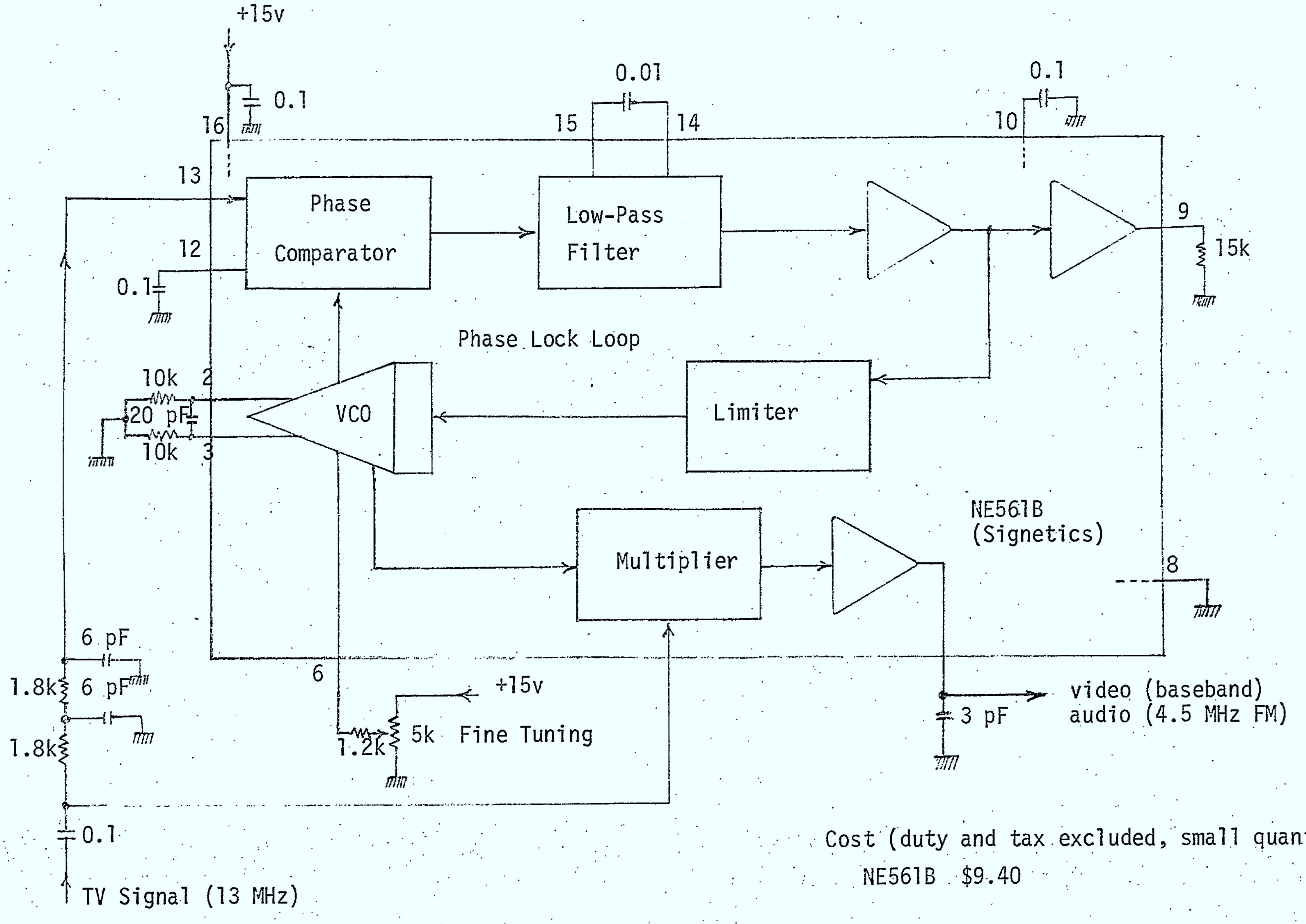


Costs (duty and tax excluded, small quantity prices)

XR-215	$6.30
LH 0005 CH	$28.50
MD 108	$7.00

Fig. E-1 CIRCUIT FOR COHERENT DEMODULATION OF A TV SIGNAL

The phase lock loop provides the reference frequency for coherent demodulation.



Cost (duty and tax excluded, small quantity price)
NE561B $9.40

Fig. E-2 INTEGRATED CIRCUIT FOR COHERENT DEMODULATION OF A TV SIGNAL

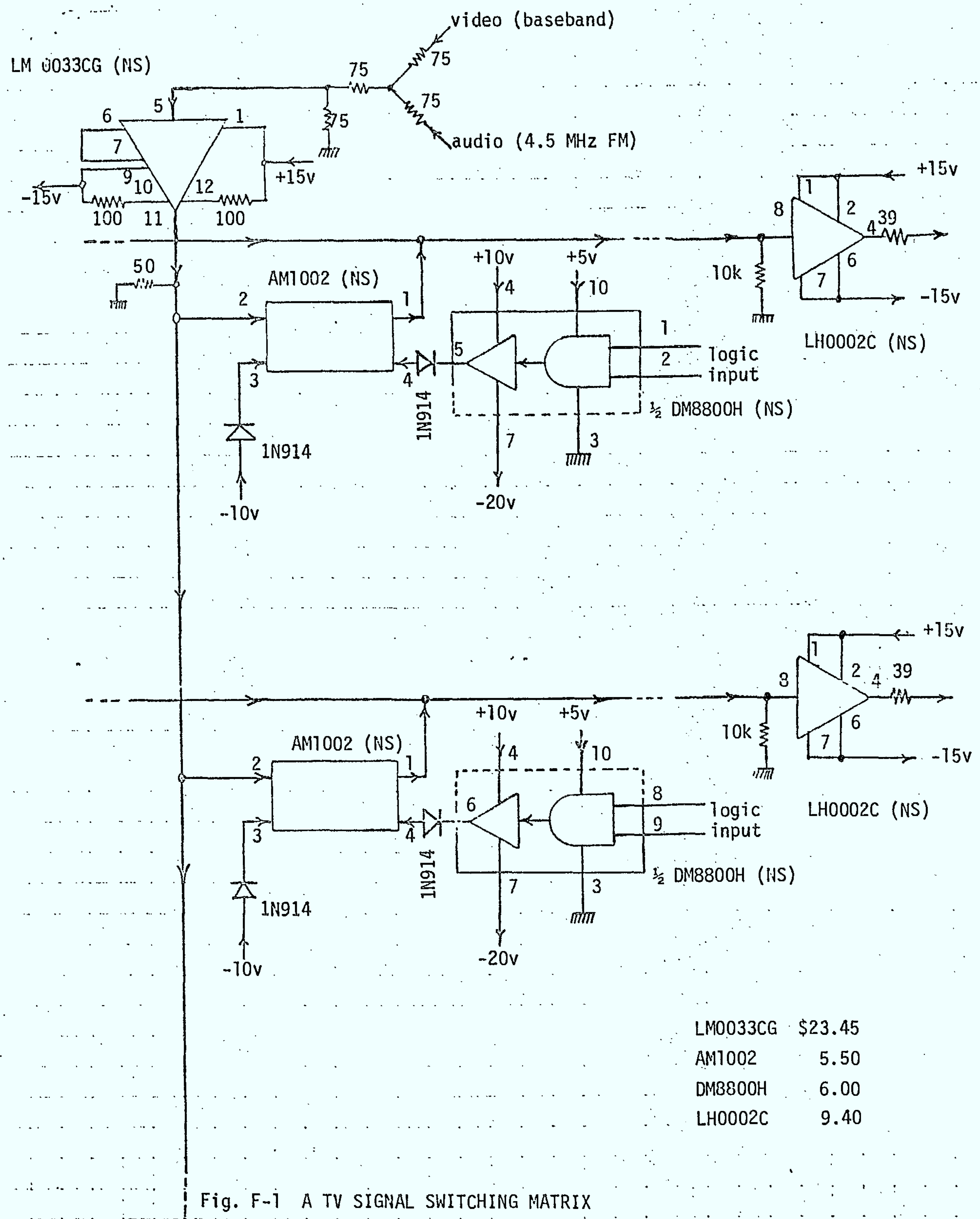
A phase lock loop and a multiplier (demodulator) are included in the same package.

APPENDIX F

CONCEPTUAL DESIGN OF A TV SWITCHING MATRIX

Figure F-1 shows a conceptual design of a switching matrix for baseband TV signals. Whether the system will perform adequately at subcarrier frequencies (13 MHz or 19 MHz) depends on the isolation provided by the solid state switch AM10002 manufactured by National Semiconductor Corp. as well as on the care exercised in designing the layout of the printed circuit board.

The TV signal is supplied to the common bus by an LM0033CG voltage follower manufactured by National Semiconductor Corp.. The unit has a very low output impedance (6 Ω) and can supply up to 250 mA of current. Many subscriber lines therefore can be connected to the common bus-bar. The AM1002 switch is controlled by the central processor unit (CPU) through a TTL buffer DM8800H manufactured by National Semiconductor Corp.. When the switch AM1002 is closed, the TV signal is connected to the current amplifier LH0002C manufactured by National Semiconductor Corp.. The unit acts as a buffer and delivers the signal to the following stage. Experimental work is required to determine the performance of this design.



LM0033CG	$23.45
AM1002	5.50
DM8800H	6.00
LH0002C	9.40

Fig. F-1 A TV SIGNAL SWITCHING MATRIX

Current amplifiers LH 0002 C are connected to the common bus by CPU controlled semiconductor switches AM1002.